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Neuropsychological Effects of Ambient Air Pollution on Infants and Children

FINAL REPORT

POST DOCTORAL FELLOWSHIP FOR WOMEN 2011- 12

Dr. Madhulika Sharma
Post Doctoral Fellow
UGC Ref. No. : PDFWM-2011-12-GE-UTT-10259 (SA-II)
Research Centre : Dept. of Home Science,
Juhari Devi Girls P.G. College, Kanpur
Resi. : 12/411-A, Behind Church, Gwaltoli, Kanpur
Mob. : 8726259999

Dr. Veena Nigam
Supervisor
Dept. of Home Science,
Juhari Devi Girls P.G. College, Kanpur

CERTIFICATE

Dr. VEENA NIGAM
Supervisor

Department of Home Science
Juhari Devi Girls Post Graduate College
Kanpur

I hereby certify that the final report of the Post Doctoral Research work entitled "**Neuropsychological Effects of Ambient Air Pollution on Infants and Children**" submitted to University Grants Commission, New Delhi under the ***"Post Doctoral Fellowship for Women 2011-12"*** scheme, is a record of bonafide research work carried out by **Dr. Madhulika Sharma,** under my guidance and supervision and that the work has not been submitted elsewhere for a degree.

Dr. Madhulika Sharma has submitted the ten half yearly progress reports during the period of five years (28th November'2013 to 27th November'2018) of the Post Doctoral Fellowship (Award letter no. and date: F-15-1/2011-12-GE-UTT-10259(SA-II) dated 01/11/2013) as required under the ***"Post Doctoral Fellowship for Women 2011-12"*** scheme guidelines of University Grants Commission. I am fully satisfied with her work.

Date :

(VEENA NIGAM)

Acknowledgment

Availability of fresh air is evolving as one of the major crisis of the day in cities. The impact of air pollution has mainly been recognized on both the mortality and morbidity of the population. It's high time to pay attention to the subtle and sub-clinical effects of ambient air pollution on brain functioning of the masses, to save our future generations from one of the most devastating forms of environmental pollution, so that they may compete globally in scoring high on emotional intelligence and designing devices and apps having artificial intelligence.

The present research work is an attempt to explore the impact of air pollutants on neuropsychological functioning of one of the most vulnerable populations; the infants and young children.

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Kanpur, **(Madhulika Sharma)**
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Executive Summary

The present research is a unique ex-post-facto field study in which the risks associated with the early exposure to ambient air pollution on neuropsychological development of children starting from infancy till school-going stage were investigated. The study is unique in nature as it considers the cumulative measures of environmental influences i.e., ambient air pollution along with other socio-demographic factors like SES, gender and family size and its impact on brain functioning. These cumulative measures of environmental influences/ exposures were termed as "exposome" by Wild (2005). The present study is unique as it involves systematic investigation of impact of ambient air pollution exposures on brain functioning of three age groups (0-2 years, 3-6 years and 7-12 years) through neuropsychological assessment in a real setting.

Kanpur city; a highly polluted city of North India having global ranking of fourth most polluted city (WHO, 2015) was considered as the locale for study. Exposure to ambient air pollution was assessed in terms of PM_{10} levels using the six year (2011-2016) records of environmental monitoring data of state pollution control board (UPPCB). Ambient particulate matter (PM_{10}) was considered especially for the study as these inhalable particles due to their minute size may easily enter the human brain/ central nervous system directly through nasal olfactory mucosa or through leakage in blood brain barrier (Genc,S. et al, 2012; Lucchini et al, 2012; Oberdoster et al, 2004; Peters et al, 2006). Various industrial, commercial (highly congested with traffic) and residential areas of the city were surveyed/ explored. The city was divided into three levels on the basis of PM_{10} levels; low polluted (PM_{10} twice the standard value of 60μg/m^3), moderately polluted (PM_{10} thrice the standard value of 60 μg/m^3), and highly polluted (PM_{10} four times the standard value of 60μg/m^3). An area on the outskirts of the city, away from the city traffic and industries, surrounded by greenery, having PM_{10} within the standard limits (60μg/m^3) was considered as the background area or unexposed area. A sample of 720 healthy, full-term children; 25 infants, 80 preschoolers and 80 school-going children from each of the four areas were selected through purposive random sampling. Utmost care was taken to select the infants and children whose mothers had been residing in the study areas since five

years at least. Personal data and prenatal history of the children were recorded through interview schedule for parents. Children of similar income groups were selected to match them on parental education, income, diet and home environment factors. SES was analyzed using the modified Kuppuswamy's scale (Singh, Tulika etal, 2017).

Neuropsychological assessment i.e., measurement of performance of children on standardized neuropsychological tests, one of the most reflective markers of neurotoxicity of environmental toxins (Harvey, Phillip D., 2012) was used as tool to study the neurobehavioural risks associated with ambient air pollution. Culturally sensitive popular standardized psychological tests were used as per the acceptability of children of the three age groups (White, R.F. etal, 2009). Development Assessment State for Indian Infants by Dr. Pramila Pathak (Indian adaptation of Bayley's Scale for Infant Development), Indian adaptation of Stanford Binet Test of Intelligence by Kulshreshtha and a test battery (assessing the domains of full IQ, attention, executive function, vocabulary, visuo-spatial ability, immediate recall memory, delayed recall memory, recognition memory, processing accuracy and manual dexterity) on the guidelines similar to Neurobehavioural Core Test Battery (NCTB) were used to assess the neuropsychological development of infants, preschoolers and school-going children respectively. All the short tests used for school-going children were part of standardized tests namely, Developmental Screening Test by Bharat Raj, Malin's Test (Indian adaptation of WISC), SB Test by Kulshreshtha and PGI Memory Test. The data collected was analysed using ANOVA, chi-square test, odds-ratio and correlation methods through SPSS.

The overall motor and mental development of all the three age groups; infants, preschoolers and school-going children was found to be adversely affected by the levels of PM_{10} of the city. On studying the variables of neuropsychological measures in specific, the basic forms of mental abilities of infants like visual and auditory cognizance motor skills like neck movement and control revealed no significant difference due to exposure to various levels of PM_{10}. Similarly in case of school-going children the basic form of memory; the recognition memory or iconic memory was not found to be affected by air pollution.

Attention, working memory and immediate memory were the areas

which revealed a distinctive and significant effect due to air pollution exposure among school-going children. However, in case of infants and preschoolers, PM_{10} levels ascertained no significant effect on their immediate memory which may be because of more matured and developed mental skills of the school-going children.

Apart from this, language development and comprehension among infants and preschoolers, visual perception and reasoning among preschoolers, visuo-spatial ability and perceptual accuracy among the school-going children were the age-specific neuropsychological measures which revealed major differences in PM_{10} exposed and unexposed areas.

A substantial variance (7% to 15%) was investigated due to air pollution in determining the mental ability measures like IQ, attention, executive function, vocabulary, immediate recall, and manual dexterity measures like right hand dexterity (RHD) and right hand dexterity (LHD) among school-going children through multiple regression analysis.

The confounding effect of age was more in case of neuropsychological measures involving motor coordination; maturity of nerve-muscle coordination like visuo-spatial ability (block design test), perceptual accuracy (coding test) and manual dexterity (RHD, LHD & BHD) among school-going children. SES and gender also reported meager positive associations with working memory and vocabulary of school-going children.

The results of the present study suggest that several important domains of brain function of young children may be affected by the cumulative effect of various constituents (black carbon, sulphates, nitrates, minerals, dust etc.) of ambient air pollution in general and particulate matter in specific. If this degradation in cognitive performance is long-term or irreversible due to genetic changes via mutagenesis and epigenetic mechanisms (Miller & Jones, 2013), it could be of great societal concern for the population affected.

Publications during the period of Post Doctoral Fellowship

Paper published

1. Sharma, M. and Nigam, Veena. 2014, Problem of Hyperactivity in Children: An Overview of Recent Literature *Journal of National Development,* Vol. 27(1), pp 83-88.
2. Sharma, Madhulika and Nigam, Veena. (2015). Effect of Vehicular Pollution on Mental Performance of School Going Children (11-15 Years) in a North Indian City. *Asian Journal of Environmental Science*, **10** (2).
3. Sharma, Madhulika (January-March, 2017). Combating Gender Stereotyping through Education in India. *Contemporary Social Sciences*, **26** (1) 71-80.
4. Sharma, Madhulika and Nigam, Veena, April, 2018. 'Effects of Prenatal Exposure to Ambient Air Pollution on the Development of Infants'. *International Journal of Research*, 5 (12) 2658- 2666.
5. Sharma, Madhulika, 2018, 'Health Hazards of Ambient Air Pollution during Infancy and Childhood: An Overview', *Journal of National Development*, 31(1), 236-244.

Papers presented in Seminars

1. "Hyperactivity in Children: A Growing Concern of Parents in Cities" in the International Conference on 'Scientific and Technological Advancements: Social Issues and Health Concerns' organized by School of Home Science, Babasaheb Bhimrao Ambedkar University, Lucknow on 18th-19th February, 2014.
2. "Hazards of Ambient Air Pollution to The Health of Infants and Children" in the National Seminar on 'Urbanization and Environmental Change in India- Problems and Challenges' organized by Department of Geography, Meerut College, Meerut on 29th and 30th March'2014.
3. "Effect of Vehicular Pollution on the Physical Health of Adolescents" in the National Conference on 'Technological Empowerment of Women at Grassroot' organized by Department of ECM, College of Home Science, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur on 6th and 7th September, 2014.
4. "Barriers in Implementation of Inclusive Education in India" in the

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5. "The Relevance of Mahatma Gandhi's Philosophy of Early Childhood Education in the 21st Century" in the International Seminar on "World Crisis and the Gandhian Vision" organized by Ismail National P.G. College for Women, Meerut on 20th & 21st January'2015

6. "Shadow of Indo-Pak Relations on Common Regional Cultural Reminiscences: A Contemporary Perspective" in the National Seminar on "India-Pakistan Relations: Issues and Challenges" organized by Department of Defence Studies, Meerut College, Meerut on 12-13 September'2015.

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9. "Economic Empowerment of Rural Women through Self Help Groups" in the National Seminar on "Development of Women Entrepreneurship in India" organized by Department of Economics, Ismail National P.G. College for Women, Meerut on 18th- 19th February'2017.

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2. *Bachchon (6-12 varsh) me Ekagrata evam Sochane ki Kshamta Viksit Karne ke liye Kuch Kriyaaon ka Sankalan*

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List of Abbreviations used in the report

Abbreviation	Full Form
AAP	Ambient Air Pollution
AAQ	Ambient air quality
ADHD	Attention Deficit Hyperactivity Disorder
ANOVA	Analysis of variance
ASD	Autistic Spectrum Disorder
BA	Background Area
BHD	Both Hand Dexterity
BSID	Bayley's Scale of Infant Development
CPCB	Central Pollution Control Board
DASII	Developmental Assessment Scale for Indian Infants
DMeQ	Mental Development Quotients
DMoQ	Motor Development Quotients
DSB	Digit Span Backward
DSF	Digit Span Forward
DST	Developmental Screening Test
HAP	Hazardous Air Pollutants
HPA	Highly Polluted Area
IITK	Indian Institute of Technology, Kanpur
IQ	Intelligence Quotient
LHD	Left Hand Dexterity
LPA	Low Polluted Area
LPG	Liquid Petroleum Gas
MPA	Moderate Polluted Area
NAQ	National Ambient Quality
NHAI	National Highway Authority of India
No_2	Nitrogen di oxide
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Poly Chlorinated Biphenyles
PM	Particulate Matter
Pm_{10}	Particulate matter of size $\leqslant$ 10µm
$PM_{2.5}$	Particulate matter of size $\leqslant$ 2.5µm
RHD	Right Hand Dexterity
SES	Socio Economic Status
SO_2	Sulphur di oxide
UPPCB	Uttar Pradesh Pollution Control Board
USEPA	United States Environmental Protection Agency

Chapter-1

INTRODUCTION

The problem of air pollution has increased manifolds in the last few years globally and nationwide. As per the 2016 Environmental Performance Index, more than 3.5 billion people, i.e., about half of the world's population, are exposed to unsafe air quality including 75% of India's population. As far as the geographical area is concerned, India has 13 cities in world's top 20 most polluted cities (Ambient Air Pollution Database, WHO, 2016). Industrial emissions, automobile exhaust, increasing number of vehicles, combustion of fossil fuels and improper waste management are the major sources of toxic air pollutants in the cities. Due to the emission of hazarduous air pollutants, the health of the people residing in the near vicinity of industries, roads and commercial hubs especially the infants and young children are more at risk.

According to the recent database, ambient air pollution has been linked to diseases and infections that kill around six lakh children under-five years of age per year (Rees, N., 2016). A study even shows that about 2.2 million school children in Delhi are growing up with irreversible lung damage which they will never recover (Ghosal, A & Chatterjee, P., 2015). The number of premature deaths due to outdoor air pollution is projected to increase from 3 million people globally in 2010 to a global total of 6 to 9 million people in 2060 (OECD).

In addition to the general health and mortality risks, the sub-clinical neurotoxic effects of air pollutants are one of the most concerned health effects being studied worldwide today. Reduced cognitive and psychomotor development are found to be the major brain functions affected among children and adults due to increase in exposure to air pollutants like polycyclic aromatic hydrocarbons (PAH), nitrogen-di-oxide (NO_2), sulphur-di-oxide (SO_2) and particulate matter (PM) (Perera, FP, etal, 2006; Tang, D etal, 2008; Cowell, WJ, etal, 2015 ; Porta, D, etal, 2016). Exposure to air toxins like lead, mercury and polychlorinated biphenyls (PCBs), have also been found to be associated with attention deficit, functional abnormalities, poor school performance and learning disabilities in children (USEPA, 2003; Suh, HH, 2000; Goldman LR, Shannon MW, 2001). Exposure to chemicals at current environmental levels during prenatal development can be neurotoxic

for years or even decades after exposure (Grandjean, Landrigan 2006). Various reports have linked increased incidence rates of diseases of the nervous system, such as neurodegenerative diseases like Alzheimer's and Parkinson's diseases in adults (Block and Calderon- Garciduenas, 2009) and neurodevelopmental disorders like ADHD and ASD in children (Brown, RC et al, 2005; Fombonne, E, 2009) with air pollution over the past years. The cumulative risk assessment of 40 ambient hazardous air pollutants (HAPs) from the U.S Environmental Protection Agency (EPA) and other single and multiple effect toxicological database revealed that neurological effects ranked second out of 17 health effects after respiratory effects, regardless of the data sources (Fox et al. 2004).

1.1. Ambient Air Pollution (AAP) and Its Effects :

Ambient air pollution is a multifaceted environmental toxicant that comprises a diverse mixture of particulate matters (PMs), including organic components and metals, and gases, such as nitrogen oxides, sulfur oxides, and ozone.

About 188 pollutants are listed as hazardous air pollutants (HAPs); those pollutants that are known or suspected to cause cancer or other serious health effects such as reproductive effects or birth defects or adverse environmental effects (USEPA, 2000). Particulate matter (PM), SO_2, NO_2, CO, (PAH), ozone, lead are the major air pollutants measured by the Central Pollution Control Board (CPCB), India under the National Ambient Air Quality Monitoring (NAAQM) programme. These air pollutants are released mainly from anthropogenic sources like industrial establishments, automobiles, domestic cooking and space heating (Fig. 1.1).

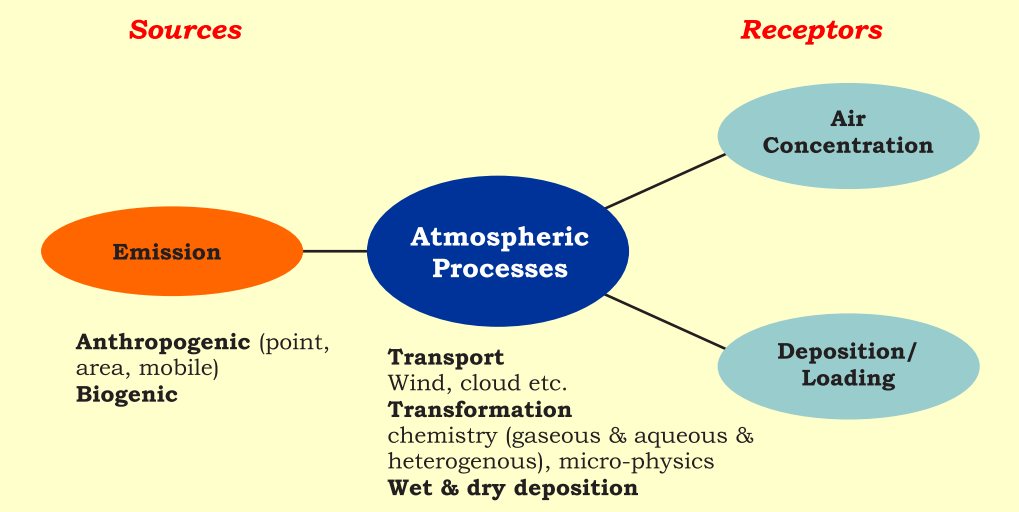


Fig. 1.1 : Air Pollution System

Out of these air pollutants, particulate matter; inhalable and respirable particles of diameter less than 2.5 micron ($PM_{2.5}$) and of diameter less than 10 microns (PM10) are considered to be the most hazardous for human health. They are a complex mixture of dry solid fragments, solid core with liquid coatings and small droplets of liquid. These tiny particles vary greatly in shape, size and chemical composition. The very complex physical and chemical nature of PM makes it challenging for the researchers to study its biological effects on humans and animals. They mainly constitute black carbon, sulphates, nitrates, minerals, dust etc.. Particulates (PM) are highly carcinogenic and have been classified in Group I Carcinogens because of their ability to penetrate deep into the lungs and bloodstreams (IARC).

The type of pollutants emitted in the air may vary from place to place depending on the sources and meteorological parameters like wind speed, wind direction, rainfall, relative humidity, temperature, barometric pressure etc. Some pollutants remain airborne; others deposit into and contaminate land and water. The primary pollutants like coarse particles, sulphur dioxide, nitrogen oxides and carbon mono-oxide remain in the same chemical form as emitted. While, some pollutants react in the atmosphere to produce other harmful substances which are known as secondary pollutants. Ground level ozone is an example of a secondary pollutant formed by chemical reaction of volatile organic compounds and nitrogen oxides in the presence of sunlight. These toxic air pollutants either remain in the air or enter the human receptor body.

Thus, the air pollution system may be depicted as given in the figure no.1.1.

The toxic air pollutants enter human body mainly through breathing. However, they may enter the body through contaminated water, soil, food or absorbed through the skin also. Children, pregnant women, old people and people suffering from various respiratory diseases are found to be more susceptible towards these toxic air pollutants. Once a pollutant is inhaled inside, it can stay in the lungs, be exhaled or move into the blood from the lungs or from the digestive system or skin.

In the blood it is carried to all parts of the body. As it moves around the body, a pollutant can undergo chemical changes and trigger pro-inflammatory responses (Gonzalez- Flecha, 2004). Toxic air pollutants can cause health problems by interfering with normal body functions. Most commonly they change chemical reactions within individual cells, the building blocks of living things. These changes can kill cells, impair cell function, or re-direct cell activity. The results can be damaged organs, birth defects when the cells

of an unborn child are damaged, or cancer that develops when cells begin to grow at an uncontrolled rate. The mechanism involved in the cellular damage and various pathological conditions inside the body due to the toxic pollutants like PM has been very well discussed by Elisa Ghelfi (2011) of Department of Environmental Health, Boston, USA in her paper on 'Air Pollution and Reactive Oxygen Species'. Free radicals and oxidative stress have been implicated in inflammatory response after exposure to particulate matter (PM) (Donaldson etal, 2005). Both organic and transition metals present in PM are able to generate free radicals. Free radicals are active molecules with an unpaired electron. In biological settings free radicals are potentially very dangerous since they can react indiscriminately with neighboring molecules in order to acquire one electron. This process of electron stealing leads to oxidation and often inactivation of target molecules and cellular damage. Excessive amounts of Reactive Oxygen Species (ROS) is referred to as oxidative stress and contributes to depletion of antioxidants, cause aberrant cell death and have been implicated in a variety of pathological events like cardiovascular diseases, inflammation and neurodegenerative diseases (Chen & Nadziejko, 2005).

Some toxic air pollutants such as lead, mercury, and dioxins degrade slowly or not at all. These pollutants may bioaccumulate in humans directly or through animals. Lead is mainly emitted through leaded petrol and industries. Industrial emissions, especially from coal-fired power plants, are the leading source of environmental mercury. Although the levels of airborne mercury may not be hazardous, mercury deposits into soil and surface waters and ultimately accumulates in fish which is further consumed by people (American Academy of Pediatrics, 2001).

The major air pollutants, their sources and their toxic effects on general health of people have been briefly described below in table no.1.1. Depending on the level of exposure, these air pollutants may cause various physical health problems. The initial symptoms of toxicity of ambient air pollutants are respiratory problems like coughing, sneezing, breathing problem, dizziness etc. If the exposure to these air pollutants continues, it may affect other organ systems like cardiovascular and neurological systems. The molecular and cell toxicity may also induce a variety of cancers in the long term (Loomis D, Huang W, Chen G, 2014; Rodopoulou S, et al, 2014; Carugno M etal, 2016). In case of long term or chronic exposures they may even prove to be fatal.

Table no.1.1 : Major air pollutants and their short term and long term effects on human health

Air Pollutant	**Major Sources of Emission**	**Short term Effects**	**Long term Effects**
Particulate Matter (PM_{10} & $PM_{2.5}$)	Motor engines, industrial activities	Wheezing cough, dry mouth, breathing problems or decreased lung functions	Respiratory diseases like asthmatic bronchitis and COPD, heart disease like cardio - pulmonary and cardiac dis - rhythmias, cancer .
Carbon mono oxide	Burning coal, wood, motor engines, industrial activities	Headache, weakness, dizziness, nausea, vomiting	Cardiovascular diseases
Sulphur-di-oxide	Burning of fossil fuel, natural volcanic processes, industrial activities	Damages to the eyes (lacrimation and corneal opacity), mucous membranes, the skin (redness, and blisters), and respiratory tracts; Bronchospasm, pulmonary edema, pneumonitis, and acute airway obstruction	Respiratory irritation and dysfunction, cardiovascular diseases
Nitrogen-di-oxide	Mainly motor engines	Coughing and wheezing, eyes, nose or throat irritations, headache, dyspnea, chest pain, diaphoresis, fever, bronchospasm, and pulmonary edema	Respiratory diseases
Lead	Industrial activities; smelters, battery plants, irrigation water wells and wastewaters, leaded petrol	High blood pressure, infertility, digestive and renal dysfunctions, and muscle and joint pain, abdominal pain, anemia, aggression, constipation, headaches, irritability, reduced sensations, and sleep disorders	Damage to cardiovascular, renal, reproduc tive and nervous systems
Polycyclic aromatic hydrocarb ons (PAH)	Fuel combustion, wood fires, motor engines	Respiratory dysfunctions	Damage to CNS, cancer

Source: Ghorani-Azam, Adel et al, 2016

Why children are more sensitive towards the effects of ambient air pollution?

There are many reasons behind greater susceptibility of infants and young children towards the ambient air pollution.

I. Brain development (processes like neuron formation, differentiation, synaptogenesis, myelination etc.) extends from embryonic period to adolescence (Rice, D. & Barone, S., 2000)

ii. Prenatal exposure to outdoor air pollution has been associated with low birth weight (less than 2.5 kg or 5.5 pounds) and length, disturbed mental development spontaneous abortion and premature birth (Oostdam etal, 2003; Xu X, Sharma etal, 2010; Rich, DQ etal, 2009).

iii. Their blood-brain barrier is more permeable than adults.

iv. They have immature immune and detoxification systems.

v. Children are more active than adults, and have a higher metabolic rate than adults, children eat more food, drink more water and breathe more air than adults, and their intake of air per unit weight per day is about threefold (Gauderman and Gilliland, 2002).

vi. Children are less concerned about hygienic practices leading to greater exposure to environmental pollutants especially in the lower socio-economic strata.

vii. A child's 'breathing zone' is closer to the ground, where levels of particulate matter and some chemicals tend to be higher (Wigle, 2003).

To assess the neurobehavioural risk associated with Ambient Air Pollution among children of a geographical area, it is essential to begin with the assessment of ambient air pollution exposure.

1.2. Assessment of Exposure to Air Pollutants:

Environmental monitoring is one of the most reliable methods of estimating the population exposure to various ambient air pollutants. The variations in emissions and pollutant concentrations may be easily noted through the environmental monitoring performed on regular basis. In addition, pollutants like PM do not have any specific biomarkers or physiological assessment techniques for the assessment of all of its constituent organic and inorganic compounds.

Study of personal activity pattern or personal monitoring could prove to be a better option for assessment of individual variations in air pollutant exposure.

Ambient Air Quality monitoring is an important part of every government's environment protection plan. Environmental monitors are used to sample the air and measure the amount of pollutant present in the air. Mathematical equations are used to estimate the amount of pollutant that moves in the atmosphere. Factors affecting the stay of pollutants in the air such as humidity, wind speed and directions, height at which emissions are released are considered for estimates. The automobile emissions released in the breathing zone of human beings are said to be more harmful as compared to the emissions from chimneys at higher levels.

The Government of India monitors and assesses the present and anticipated air pollution through continuous air quality surveys under the NAMP since 1984-85.

To provide uniform yardstick for assessing air quality at national level, various countries have their own standards for different air pollutants as per the threshold level/ breakpoint concentrations set by their national agencies. (Gao, 2013 and CAQI, 2012).

The Central Pollution Control Board has identified and revised the National Ambient Air Quality Standards on November 2009 which was notified in Gazette of India as depicted below.

Table No. 1.2 : National ambient air quality standards (annual) for industrial, residential, rural and other areas:

Pollutant	**Concentration in Ambient air (annual)**	**Pollutant**	**Concentration in Ambient air (annual)**
Sulphur Dioxide	50 µg/m^3	Nitrogen dioxide	40 µg/m^3
Particulate matter less than 10 micron size	60 µg/m^3	Particulate matter less than 2.5 micron size	40 µg/m^3
Ozone	100 µg/m^3	Lead	0.5µg/m^3
Carbon monoxide	2 mg/m^3	Ammonia	100 µg/m^3

Source : CPCB

The major air pollutants monitored regularly in the city by CPCB under the National Air Monitoring Programme through its environmental monitoring stations are SO_2, NO_X and PM_{10}. The monitoring of pollutants is carried out for 24 hours with a frequency of twice a week for estimation of level of

various pollutants in the atmosphere and comparison with the above mentioned standards.

An individual's exposure to these pollutants is further decided by the estimates of breathing rate and the distance from the source of emission. The breathing rate in a healthy adult is between 12 and 18 breaths per minute. Thus, an average man breathes 22,000 times a day and takes in 16 kg of air each day (Wikepedia). The breathing rate of an average healthy infant is three times more and an average healthy preschooler and school-going child's breathing rate is half times more than an average healthy man making them more susceptible towards the adverse effects of air pollutants. Similarly, the breathing rate of a person suffering from a respiratory disease like asthma, chronic obstructive pulmonary disease (COPD), lung cancer, pneumonia, tuberculosis, and heart problems like cardiac arrest is increased much more than an average healthy person. Thus, they may inhale more amounts of toxic pollutants as compared to an average person. Variations may occur depending on how much time a person remains indoor or outdoor and in workplace. Young children spend most of their time playing outside.

After estimation of the exposure to air pollutants, there is a need for identification of health risks (neurotoxic effects in this study) associated with the exposure to ambient air pollutants.

The studies on the toxic effect of hazardous air pollutants on the central nervous system or brain are broadly classified into two on the basis of approaches of study; one studying the biological changes in the structure of brain known as neuroscience and the other focusing on the functional changes of the nervous system, the neuropsychology.

1.3. Changes in Brain Structure due to Exposure to AAP

The human nervous system is divided in two: the central nervous system (CNS) consisting of brain and the spinal cord and the peripheral nervous system consisting of the nerves and ganglia connecting the central nervous system with rest of the body. Neurons, the basic unit of nerves are spread throughout the body including the sense organs. These billions of neurons are connected through synapses containing chemical substances known as neurotransmitters. Electrical signals are transmitted through these neurons from the brain or body to the specific recipient cells. Every function involving sensing, controlling and processing may involve many regions of brain and nervous system.

The process of development of nervous system initiates from the embryonic period and ends during adolescence. The process involves many steps including formation of brain, formation of neurons, migration of neurons, formation of synapses, myeleination of neurons etc. (Rice and Barone, 2000). During the development of embryo, approx two weeks after gestation, neural crest cells migrate to the middle forming a neural tube. The anterior portion of the neural tube differentiates into the regions of brain; forebrain, mid brain and hind brain and the posterior portion develops into spinal cord. Finally the six main parts of the brain are formed; the cerebrum, diencephalon, mesencephelon, cerebellum, pons and medulla oblongata. The cerebrum is the largest and most distinctive part of the brain (Figure no.1.2).

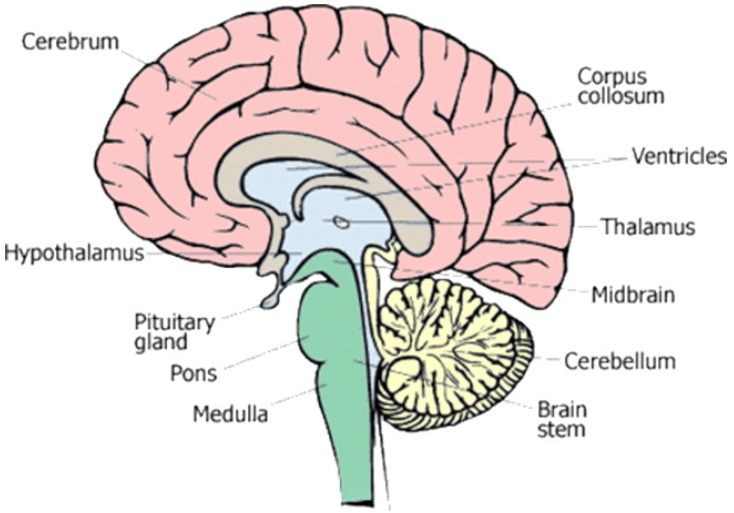


Fig. 1.2 : Structure of Human Brain

On the basis of types of neurons present in the brain structure, the brain is divided into two: white matter and grey matter. The white matter consists of myelinated neurons covered with white coloured myelin sheath

Majority of the studies on histological and biological changes in the CNS due to exposure to various air pollutants have been conducted on animals like rodents and nonhuman primates. A few studies have observed the changes in structure and histology of brain of humans after exposure to ambient air pollution using neuroimaging techniques like magnetic resonance imaging (MRI), immune-histochemistry and electron microscopy. High cost associated with the use of these technologies and ethical issues involved in studying human samples are the major constraints behind very few human studies in the field. On the basis of these studies the effects can be broadly summarized as below:

i. Deposition of particles in the brain:

The particles may enter the brain through various means. Pollutants can enter the brain through direct translocation. Animal studies have shown that inhaled particles can be translocated to the brain via olfactory nerve that connects the nose and the brain directly (Elder, G etal, 2006 and Oberdorster, S etal, 2004). Some particles depending on the size translocate from the lungs by penetrating pulmonary tissue and entering the blood capillaries. Through circulation they may reach other organs like brain. The blood brain barrier is supposed to inhibit harmful particles from entering the brain. However, fine particles are able to leak through the endothelial tight junctions of the blood brain barrier (Elder, G. etal, 2006).

ii. Oxidative stress due to free radicals and reactive oxygen species (ROS):

As the pollutants like particulate matter cross the blood brain barrier and enter the blood vessels in the brain/ nervous system, the organic and transition metals generate free radicals. These free radicals further lead to oxidation in the brain/ nervous system (Elisa Ghelfi, 2011). The nervous system, particularly the central nervous system (CNS), is vulnerable to oxidative stress because it has high metabolic demands, high energy use, widespread axon and dendrite networks, high cellular content of lipids and proteins, and low levels of endogenous scavengers, such as vitamin C and superoxide dismutase, which, to some extent, may be due to the CNS being isolated (Pajovic SB et al, 2003). The CNS in a child could be especially susceptible to oxidative stress from environmental toxicants because of its immature blood brain barrier and a wide range of exposures.

iii. Neuro-inflammation and neuro-degeneration:

The initial active immune defence in the central nervous system is generated by the action of microglia. These microglia are a type of glial cells that reside in the brain and the spinal cord. They respond to tissue insult with a complex array of inflammatory cytokines and actions. Cytokines are recognized as the prime components of an intrinsic brain immune system (Streit, Mark etal, 2004). This neuro-inflammation may further lead to a more chronic and sustained cycles of injury, loss of neurons and neuronal dysfunction (Bellucci, Westwood etal, 2004). Neuro-degeneration is the term for overall

progressive loss of structures or function of neurons and axons in the CNS. A cytokine called interleukin-1(IL-1) generates/ expresses cyclooxygenase (COX2), an inducible enzyme in the inflamed tissues. The changes in expression of COX2 was examined in human brain samples from lifelong residents of large cities with severe air pollution (exposed) and control subjects from small cities with low air pollution levels (unexposed) in Mexico (Colderon, GL Et al, 2013). The high COX2 expression being characteristic of neurological disorder like Alzheimer's disease, it was further suggested that air pollution may increase the risk of neurological disorders.

iv. White matter lesions:

White matter is primarily found in the interior part of the cerebrum, the largest and most distinctive part of the human brain. White matter is mostly made up of mylienated axons and a few cell bodies. The pale white colour is due to the myelin sheath that surrounds axons. Disrupted neurons in white matter may be seen in form of lesions. Residents of highly exposed areas of Mexico City were found to have white matter lesions in higher proportion as compared to the residents of low exposed area of Polotitlan in a heirrarchical regression model adjusted for age and gender (Colderon, GL Et al, 2013). White matter lesions have also been reported due to the toxic effects of air pollutants. A clear connection has been found between these lesions and decreases in brain volume, loss of memory, vision and cognitive impairment (De Groot, De Leeuw etal, 2002).

1.4. Neuropsychological development of children and factors affecting it:

The mental and motor development of a child is controlled by the functioning of brain or the nervous system. Thus, all the behaviours related to motor and mental development are termed as neuropsychological development of a child. The neuropsychological development of a child is mainly affected by two broad factors; the genetic factor or the genotype of the child and the environment of the child which includes the socio-economic status of the family, the physical and psychosocial environment of the child as also shown in the Figure no. 1.3.

The role of nature/ genes vs. nurture/ environment in the development of a child has been an issue of controversy since many years. The genetic makeup of a person is reflected in the phenotypic characteristics like body build, colour of eyes and intelligence as well. However, as per the recent

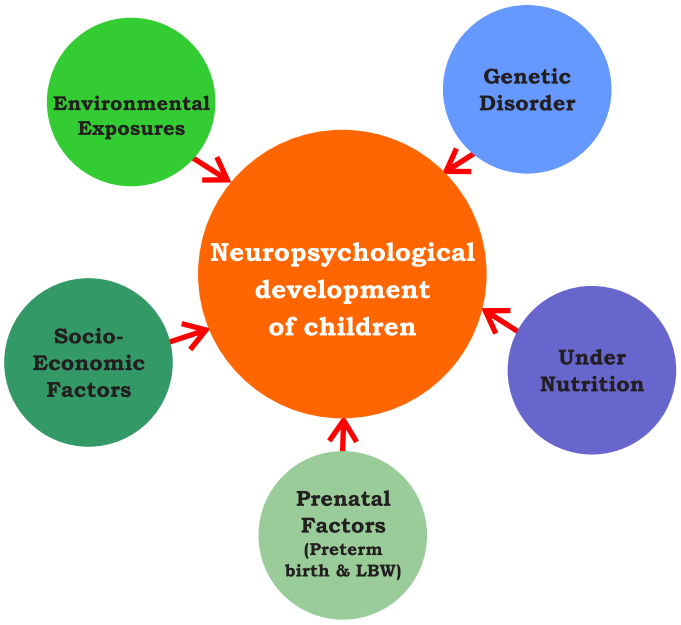


Fig. 1.3 : Major Factors affecting (Risks associated with) Neuropsychological development of children

observations, genome wide association studies (GWAS) for cognitive functions have revealed that genetic variants identified explain a small proportion of phenotypic (observable) variability (Neale, BM etal, 2008 and Need, AC etal, 2009). It has been further proposed that the environmental exposures cause permanent genetic changes via mutagenesis and also have long-term impact on gene expression through epigenetic mechanisms. Epigenetic mechanisms are central to differentiation and development, impacting function before birth and throughout life (Miller, GW and Jones, DP, 2013). Dr. Christopher Wild in support of the view coined the term "exposome" which "encompasses life-course environmental exposures (including lifestyle factors), from the prenatal period onwards" (Wild, 2005). Jones etal, 2012, included chemical exposures within the broader context of diet, behavior and other exogenous and endogenous agents. Hence, there is a need for better ways of assessing and quantifying the effects of environmental exposure. There is a need for new approaches for incorporating the environmental exposures in the genetic studies. According to CJ, Patel etal, the environment wide association studies could become much more powerful and complement GWAS studies (Patel, CJ, etal, 2010).

1.5. Neuropsychological effects due to exposure to Ambient Air Pollution

Due to the complex structure of brain and the whole nervous system, the functional changes resulting from the toxicity of various air pollutants are also found to be complex in nature. Depending on the age and growth of the

child's brain, there may be critical periods of development of different neuropsychological variables. Alterations in gait, visual-motor and psychomotor performances, emotional state and other behavioural parameters may be the earliest and most sensitive signs of nervous system neurotoxicity. Norton, 1986 has mentioned five categories of functional changes resulting from the toxic effects on anatomic areas in nervous system; sensory, motor, two integrative functions (symbol formation and sensory-motor integration) and emotional states associated with any of the other four functions. Figure no. 1.4 shows the five types of functional changes resulting from neurotoxicity. These functional changes can be studied through the use of various psychological tests in neuropsychology.

1.6. Assessment of neuropsychological development in children

Air pollution exposures may affect cognitive and motor skills differentially depending on the developmental stage at which exposure occurred. The frequency of exposure and a host of other variables make it difficult to separate acute, temporary effects from persistent decrements in function. The effect of prenatal exposure to ambient air pollution may be more prominent in case of 0-2 year as compared to 3-6 year old children and 7-12 years age group. The children of 3-6 years and 7-12 years will have their own activity patterns like playing outside and going to school, which can add to the prenatal exposure effects. Therefore, depending on the child's potential, various neuropsychological tests and test batteries have been used for different age groups of children in various researches to study the neuropsychological abilities as affected by AAP.

A. Infants (0-2 years):

The development of motor and mental abilities and skills in an infant is sequential in progress as studied by many child psychologists like Arnold Gessell and Jean Piaget. There are many developmental checklists available which can be used and ticked on asking the mothers. But, they are heavily biased and lack direct observation of the child. Thus, Psychological Tests have proved to be a better option for infant study. Infant development scales measuring the psychomotor and mental developments like BSID, Brazelton Test, Fagan are some of the standardized psychological tests for infants. Among these tests, BSID having the best standardization has been used extensively in assessment of the effects of lead (Bellinger D etal, 1986; Rojo MM etal, 2006), polychlorinated biphenyls (PCBs) (Gladen

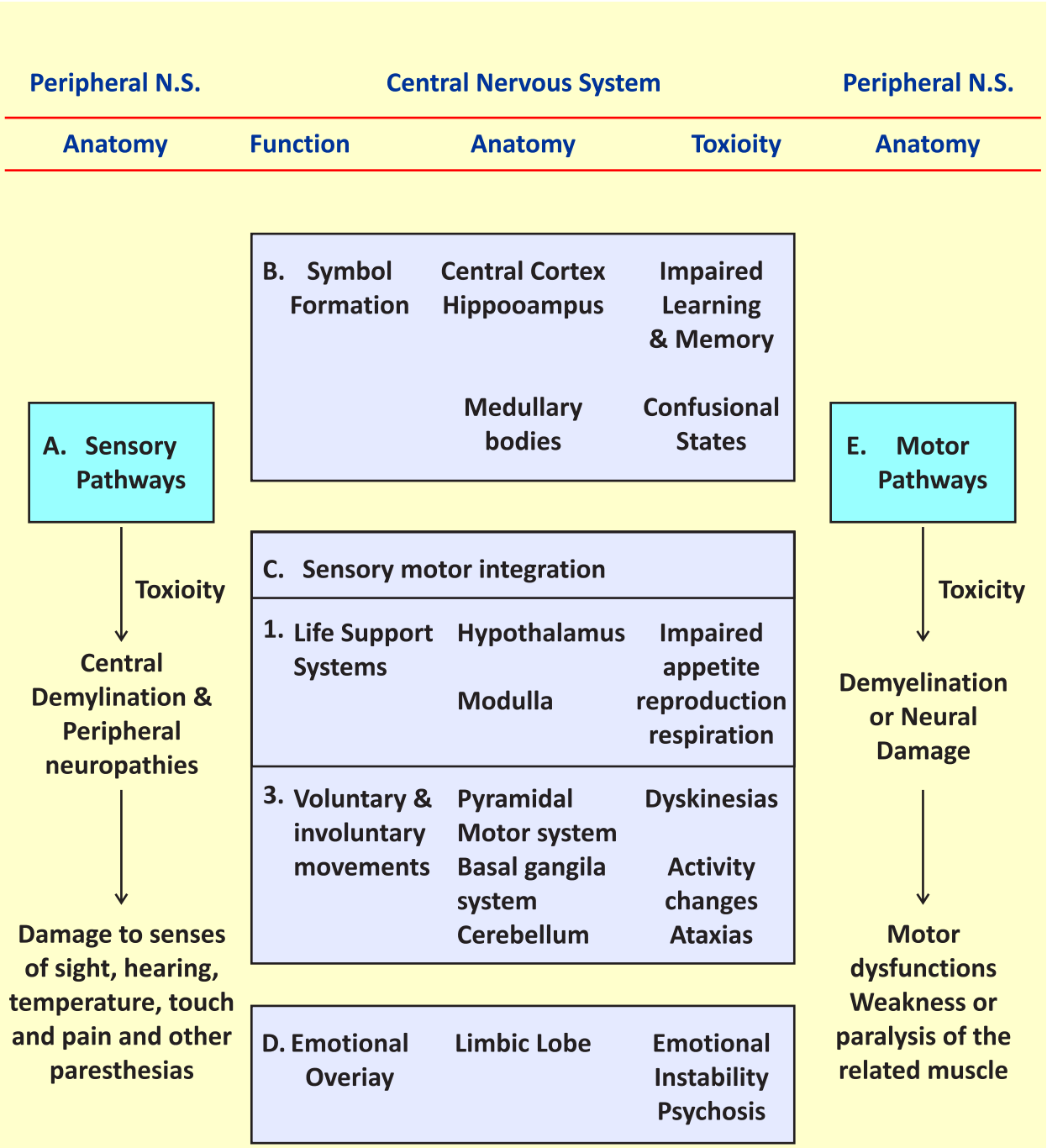


Fig. 1.4. Types of Functional Change Resulting from Effects on Anatomic Areas in The Central Nervous System (Norton, 1986)

BC, etal, 1991), methylmercury (Jedrychowski W, etal, 2007) and dichloro diphenyl dichloroethylene (Marks AR, et al, 2006; Torres-Sanchez L, et al, 2007) on children in other studies.

In addition, the BSID scale incorporates all the stages of sensory motor behavior including object permanence, eye hand coordination, circular reactions and others as per the age range of infants described in detail by Piaget.

B. Young children (3-6 years and 7-12 years)

As the child grows from sensory-motor stage (0-2 years) to the pre-operational stage (3-6 years) of Piaget's cognitive development, there is a drastic change in child's thinking process. The sensory motor behaviour of a child gets converted into behavior guided by his own understanding of the concepts, symbolic representation of objects starts as also revealed by language development during this stage. Hence, neuropsycholgical functioning of preschool children (3-6years) can be assessed using standardized Intelligence Tests covering various aspects of attention, memory, language and others.

WPPSI and Stanford Binet Scale for Intelligence are highly recommended for this age group and has been extensively used.

During 7-12 years of age the child starts interacting with the social environment through the elementary schooling. According to Piaget (1970), the child enters the concrete operational stage (7-12years) of Piaget's cognitive development. The child's maturity level of cognition raises to understanding of concrete operations, simple problems with only single aspect to be considered. Prelogical thinking level is visible in its reasoning. Thus, the 7-12year child can be assessed for more specific functions like perceptual accuracy, visuospatial abilities, executive function etc. more accurately as compared to the younger children; 0-2 years and 3-6 years. Hence, neuropsychological functioning of school-going children (7-12 years) can be assessed through administration of standardized domain-specific tests.

Various cognitive domains identified for young children for studying neuropsychological effects of toxic environmental pollutants are as follows.

i. **General Intelligence:** It is the general ability of an individual to think rationally, act purposefully and deal effectively with his/ her environment.

ii. **Attention:** It is the capacity to focus on and attend to a stimuli over a period of time.

iii. **Executive Function/ Working Memory:** It includes capacities to learn and manipulate stimuli.

iv. **Language/ Verbal Skills:** It includes basic language skills like capacity to produce phonemes, knowledge of vocabulary, speech comprehension, reading and writing. It covers two broad aspects of expressive and recetive language.

v. **Visuospatial Abilities:** They are non-verbal abilities involving processing and manipulation of visual designs, the physical or spatial aspect of environmental objects or constructional skills.

vi. **Learning & Memory :** Memory is an ability to retain and reproduce impressions once perceived intentionally. Learning of new information, retention of information over shorter and longer delays and retrieval of information from the memory stores can be assessed using both recall and recognition aspects.

vii. **Motor skills :** They include the capacity to carry out motor activities and are generally assessed using the hands or manual motor dexterity with evaluation of speed and accuracy in case of children above two/ three years.

viii. **Processing speed and accuracy tests :** They include processing of mental representations with speed and accuracy i.e., with minimum errors.

Several test batteries like the Neurobehavioural Core Test Battery (NCTB) by WHO (World Health Organisation), Finland's Institute of Occupational Health (FIOH) Test Battery and the computer administered Neurobehavioural Evalution System (NES) comprising of motor performance test, auditory memory / learning test, attention test, visual perception / vigilance test and perceptual motor speed tests have been proposed and used to study the toxic effect of various pollutants viz. carbon monoxide, lead, petroleum solvents, toluene, xylene etc. on human beings. These test batteries have also been adopted by various government and private agencies like NIOSH (National Institute for Occupational Safety and Health) to study the impact of vari ous environmental pollutants on different behavioral parameters (Anger, 1989).

In recent years, domain-specific neuropsychological tests have received more attention in behavioural toxicology because of their sensitivity to prenatal exposure to environmental toxicants. In addition, it has been argued that these tests provide more insight into the underlying central

nervous system (CNS) damage that may be associated with exposures. There is a significant literature that links impaired performance within individual domains or patterns of impaired and intact performance across domains to specific types of brain damage (structural, neural system, neurotransmitter) (White, RF etal, 2009).

The latest research approach in toxicology studies incorporates both IQ and domain-specific psychological tests at critical stages of vulnerability during child development.

On the basis of extensive review of literature the major studies investigating the neuropsychological effects of various toxic air pollutants using various neuropsychological tests have been listed in the table no.1.2.

Table no. 1.3 . Thematic review

Sr. No.	AUTHOR	Year	Theme
1.	Saxena & Saxena	1988	The research focused on the effects of long-term, low-dose exposure to lead on the performance of 150 workers from a battery factory.
2.	Gupta & Rastogi	1989	The study examined the neurotoxic effects of exposure to vehicular pollution and its duration, on visual acuity, perceptual vigilance, visual & auditory reaction time and memory of traffic constables.
3.	Sinha, S.P.	1995	The study examines and compares the neurotoxic effects of lead on the psychomotor behaviour of 960 school going children (9-14 years) of four areas; road side area, industrial area, commercial area and remote residential area of Agra city.
4.	Perera, F.P., Rauh, V., etal	2006	The study evaluated the role of prenatal exposure to urban pollutants; polycyclic aromatic hydrocarbons (PAHs), environmental tobacco smoke (ETS) and pesticides in the pathogenesis of neuro-behavioural disorders. Healthy Dominician or African-American pregnant women were studied.
5.	Calderon-Garci-duenas, L., Mora-Tiscareno, etal	2008	The study evaluates the neuro-physiological functioning and the structural brain alterations as detected by MRI of clinically healthy children that live in two significantly different urban environments (Mexico City

Sr. No.	AUTHOR	Year	Theme
			known for high concentrations of air pollutants and Polotitlan with air pollution levels within US NAAQ Standards).
6.	Suglia, S.F., Gryparis, A., etal	2008	The study examines the relation between black carbon and cognition among 202 Boston children in a prospective birth cohort study (1989-2001). Pregnant woman over 18 years, receiving prenatal care at an urban community health center in Boston were enrolled.
7.	Wang, S., Zhang, J. etal	2009	The study explores the association between traffic-related air pollution and neuro-behavioral function in children (Wang, Zhang et al. 2009). Schools located away from primary traffic roads in the north of Quanzhou and on a three-way-intersection in the centre of the city were taken.
8.	Ranft, U., Schikowski, T., etal	2009	The study investigates links between the long term exposure to traffic-related PM and the development of cognitive impairment in a cohort of elderly women.
9.	Power, M.C., Weis-skopf, M.G., etal	2011	The study examined the effects of traffic related air pollution (black carbon) on the cognitive functions of 680 (mean age 71 years) older men.
10.	Freire et al	2010	The study examined the effect of NO2 exposure on motor and cognitive abilities of 4–5 years Children measured by McCarthy Scales of Children's Abilities (MSCA) in Spain.
11.	Siddique et al	2011	The study examined the presence of ADHD in 2-17 years old children chronically exposed to high level of vehicular pollution/ PM10 in Delhi, India.
12.	Perera, F et al	2012	The study examined the effect of Prenatal exposure to PAHs on Mental development index at age 3 using Bayley Scales of Infant Development (BSID) and Child Behavior Checklist (CBCL).

Sr. No.	AUTHOR	Year	Theme
13.	Becerra et al	2013	Autistic disorders were diagnosed between children of 36 and 71 months of age due to the effect of CO. NO2, NO, O3, PM2.5, PM10 in Los Angeles, California.
14.	Guxens et al	2014	No2 was associated with reduced psychomotor development among 9482 children aged 1–6 years of six European countries.
15.	Lovasi et al	2014	The study examined the effect of Prenatal PAH exposure on the Cognitive scores of children at age 5 based on the Wechsler Preschool and Primary Scale of Intelligence-Revised (WPPSI-R) in New York, USA.
16.	Tang, Lee et al	2014	The study examined the effect of Prenatal PAH exposure on the Global IQ scores of children at age 2 based on the Gesell Developmental Scale (GDS) in China.
17.	Von Ehrenstein et al	2014	US based study examining the effect of prenatal exposure of 24 toxics, including aromatic solvents, chlorinated solvents, volatile organics, total PAHs, and metals on Autistic traits of 31–71 months children.
18.	Guxens et al	2015	Sweden (I), the Netherlands (I), Italy (I), Spain (III) Birth cohorts and child cohort study examining the effect of prenatal exposure of Nox, PM2.5 and PM10 on Autistic traits of 4-10 year old children.
19.	Talbott et al	2015	The US case control study examined the effect of prenatal and postnatal PM2.5 exposure on the Autistic traits of children at age 3-7 years using Autism Diagnostic Observation Schedules (ADOS) and Social Communication Questionnaire(SCQ).
20.	Cowell et al.	2015	The study examined the effect of Black Carbon exposure on the Cognitive scores of US children measured by Wide Range Assessment of Memory and Learning (WRAML2) at age 6.

Sr. No.	AUTHOR	Year	Theme
21.	Windham GC et al	2006	California autism surveillance system was linked to estimated hazardous air pollutant (HAP) concentrations compiled by the U.S. Environmental Protection Agency .
22.	Newman NC etal	2013	Association between early-life exposure to TRAP using a surrogate, elemental carbon attributed to traffic (ECAT), and attention deficit/hyperactivity disorder (ADHD) symptoms at 7 years of age was explored.
23.	Lovasi GS etal	2014	Early life exposure to personal PAH exposure or selected neighborhood-level social contexts were related to cognitive test scores at age 5 years.
24.	Harris MH etal	2015	The study examined the effect of Black carbon (BC) and PM2.5exposures (LUR), and residential proximity to major roadways, and near-residence traffic density during late pregnancy and childhood on verbal and nonverbal intelligence on children at 6-10 years of age using the Kaufman Brief Intelligence Test (KBIT-2)
25.	Forns J etal	2016	Exposure to TRAPs at school was associated with increased behavioral problems in schoolchildren (7-11years). Noise exposure at school was associated with more ADHD symptoms.
26.	Grineski SE etal	2016	Impact of School-based exposure to hazardous air pollutants on individual children's academic performance (Grade point average) was studied.
27.	Porta D etal	2016	719 newborns delivered in two large obstetric hospitals were studied for the impact of Early life exposure to (traffic-related) air pollution on IQ using WSIC.
28.	Yorifuji T etal	2016	The study examined associations between prenatal exposure to traffic-related air pollution and child behavioral development milestone delays.

The perusal of above studies reveal that majority of the studies have focused on the neurotoxic effects of individual air pollutants. The cumulative neurotoxic effect of all the pollutants in the air i.e., ambient air pollution (AAP) is a nascent field of research and needs to be studied systematically and more rigorously.

1.7. Factors affecting neurotoxicity of air pollution in humans

There are some variables which have been found to affect the neurotoxic effect of air pollutants on human beings. The major ones are given below:

i. Type of Pollutants

Toxicity of the pollutant may depend on the size, solubility and chemical composition of the pollutant. Some metals like lead are more toxic to the nervous system as compared to the inorganic pollutants like inorganic tin or iron. Hydrocarbons are said to be more soluble as compared to the carbon particles (Morawska, L. etal, 2008). Various chemical forms of the same pollutant may be differentially toxic to the nervous system. In general organic compounds penetrate the brain more effectively and are absorbed more completely than inorganic compounds.

ii. Age of Receptors

The age of the individual exposed to air pollution, may affect the neurotoxicity. The exposures at an early stage of prenatal development, infancy and childhood are said to be more critical than adulthood because of rapid growth and changes taking place in the structure and functioning of brain.

iii. Dose of Exposure

Acute exposure to high doses of any toxic substance is harmful for the body system. Some pollutants are toxic even in very low doses if exposed for a longer duration. If a person has stayed for longer duration in a polluted area, the chances of neurotoxic effects are more. USEPA typically assumes that at low doses the body's natural protective mechanisms repair any damage caused by the pollutant so that there is no ill-effect at low doses. The dose-response relationship varies with pollutant, individual sensitivity and type of health effect (cancerous, non-cancerous etc.). USEPA assumes that there are no

exposures that have zero-risk for cancer. Even a very low exposure to a cancer-causing pollutant can increase the risk of cancer.

iv. Diet of receptor

Diet of an individual could play an important role in affecting the neurotoxiciy effects of various pollutants. Specifically antioxidants found in fruits and vegetables are the first line of defense against oxygen free radicals in lungs and brain. Antioxidants are free radical scavengers and they react rapidly to limit interaction with lung and brain fluid lipids and proteins (Beck Speier etal, 2005) .

Studies also suggest that antioxidant nutrients such as vitamin E, dietary flavonoids, as well as a high ratio of omega-3 to omega-6 fatty acids can protect against endothelial cell damage mediated by persistent organic pollutants (Hening etal, 2005; Majkova etal, 2011; Wang etal, 2008). Although nutritional interventions such as antioxidants have been shown to be of benefit in animal studies, more research is needed to study human variability associated with such results (Soni etal, 2010).

v. Health of the individual

Individuals suffering from any chronic illnesses like COPD, heart diseases, gastrointestinal diseases are found to be more prone to the hazardous effects of AAP as their immunity system is already weak to fight with pollutants entering the body.

1.8. Justification and statement of the problem

The present study is an extension of the Ph.D. research work on "the effects of automobile exhaust on the motor and mental development of school-going children (11-15 years) of Kanpur City" of the researcher. On getting alarming results in her Ph.D. research work on the hazardous effects of vehicular pollutants on the mental and motor performance of school-going children, the researcher was further motivated to explore the impact of overall ambient air pollution of Kanpur City on the more vulnerable sections of the society i.e., the younger age group of children starting from infancy.

Kanpur, an industrial and commercial city is the second largest city in the state of Uttar Pradesh, an important state of North India. It is a densely populated city having a population of around 4.58 million over an area of1600 sq.km. (censusindia.gov.in). Besides production, the city is a major distribution centre for finished leather products, textiles and fertilizers.

World Health Organization claims the city to be on ninth rank in terms of air pollution in the whole world. Apart from industrial emissions, increasing number of vehicles (approx. 5 lakhs registered vehicles, RTO, 2011), badly maintained roads, use of diesel generators in the commercial areas, burning of solid waste in the streets are the main sources of air pollutants in the environment. Construction and demolition work in various areas, non-paved roads, mixed traffic pattern, illegal road encroachments and meter gauge railway tracks traversing the city length further aggravate the problem.

The Air Quality Index was reported to be as high as 448 in Kanpur during November 2017 by UP Pollution Control Board (Dainik Jagran, 14 November'2017). As per the Central Pollution Control Board norms, the city falls in the 'Very Poor' category of Air Quality Index (AQI) i.e., >400, which could lead to breathing and heart problems in human beings. The level of particulate matter (PM2.5) has gone up to 427 micrograms per cubic metre; six times the standard value of 60 microgram (Dainik Jagran, 2 December'2017). The cold waves, wind velocity are further aggravating the problem. Inspite of the government's stringent measures like total ban on burning of garbage and solid waste by NGT, giving notices to industries emitting hazardous pollutants above the standards and spraying of water to suppress the dust particles, the city's situation is getting worse. Encroachments along roadsides, improper parking of vehicles and construction and demolition activities all over the city are the major reasons. As per the air quality index, the active children and adults, people with respiratory problems should stay indoors and restrict their outdoor activities.

In addition, Neurobehavioral Toxicity has initially been an area of research mainly for the study of occupational hazards of toxicity on the industrial workers and traffic policemen. Various experimental animal studies have revealed a strong relationship between various industrial and environmental toxic chemicals and neurotoxicity. Standardization and validation of neuropsychological test batteries have improved the quality of data available for risk assessment. Animal models have been extensively used in acute and repeated dose toxicity studies to establish the behavioural and histopathological end-points. Inspite of the improvements in neurotoxicity risk assessment, there is scarcity of data on the effect of exposure to low levels of environmental chemicals on the neurobehavioural development in children and neurodegenerative diseases in the elderly (USEPA, 1991). There is a dearth of studies on the sub-clinical effects of air pollutants like particulate matter on the brain functioning; cognition/ intelligence, memory

and reasoning of young children specifically in a developing country like India. The magnitude of the problem may increase manifolds in combination with lower socio-economic status factor. There is a need for better scientific studies to explore the wide spectrum of these neuropsychological effects of ambient air pollution. The dearth of neurobehavioral research in developing countries is partly due to a lack of culturally relevant test batteries. The other major reason could be greater focus on the researches related to mortality of children.

Thus, the present study is an attempt to study the subclinical neuropsychological effects of exposure to low levels of ambient air pollutants on the growing children in real social settings.

Statement of the problem: "Study of the neuropsychological effects of ambient air pollution on infants and children"

1.9. Operational Definitions of the terms:

I. **Neuropsychological Effects :** All behavioural functions which are governed by nervous system, specially by the brain are defined as neuropsychological functions. In the present study, the neuropsychological effects of AAP include full IQ, psychomotor functions, language, attention, memory, visuo-spatial ability and processing speed and accuracy.

ii. **Ambient Air Pollution:** The outdoor air pollution measured by the national body; CPCB in terms of AAQ, specifically the amount of PM10; the major air pollutant monitored through various monitoring stations of the city has been considered as ambient air pollution in the study.

iii. **Infants and Children:** Infants (0-2 years) and young children (3-6 years and 7-12 years) being more susceptible to AAP because of their developing brains were included in the study. The children just after birth i.e., during infancy (0-2 years) were studied to explore the effect of prenatal exposure to ambient air pollution indifferent areas of the city.

1.10. Objectives of the Study:

Following objectives were made to carry out the study:

i. To collect the baseline information regarding ambient air quality of Kanpur.

ii. To study the neuropsychological development of infants, preschoolers and school going children of Kanpur city exposed to ambient air pollution.

iii. To study the association between neuropsychological development of infants, preschoolers, school going children of Kanpur city and ambient air pollution.

1.11. Hypothesis (H_0) Formulated

On the basis of the extensive study of various investigations related to the effects of AAP on neurobehavioural and psychological aspects of infants and young children, the following null hypothesis (H0) were framed according to the age group of children and the neuropsychological aspects assessed:

Infants (0-2 years) :

1. There will be no significant difference between the mean values of Motor Development Quotient (DMoQ) of infants of various exposed and background areas of Kanpur.
2. There will be no significant difference between the mean values of Mental Development Quotient (DMeQ) of infants of various exposed and background areas of Kanpur.

Preschoolers (3-6years):

1. There will be no significant difference between the mean values of Intelligence Quotient (IQ) of preschoolers of various exposed and background areas of Kanpur.
2. There will be no significant difference between the mean values of Visual Perception (VP) of preschoolers of various exposed and background areas of Kanpur.
3. There will be no significant difference between the mean values of Motor Co-ordination (MC) of preschoolers of various exposed and background areas of Kanpur.
4. There will be no significant difference between the mean values of Language Development (LD) of preschoolers of various exposed and background areas of Kanpur.
5. There will be no significant difference between the mean values of Immediate Recall (IR) of preschoolers of various exposed and background areas of Kanpur.

6. There will be no significant difference between the mean values of Concept Formation (CF) of preschoolers of various exposed and background areas of Kanpur.

7. There will be no significant difference between the mean values of Reasoning (R) of preschoolers of various exposed and background areas of Kanpur.

School-going Children:

1. There will be no significant difference between the mean values of Right Hand Dexterity (RHD) of school-going children of various exposed and background areas of Kanpur.

2. There will be no significant difference between the mean values of Left Hand Dexterity (LHD) of school-going children of various exposed and background areas of Kanpur.

3. There will be no significant difference between the mean values of Both Hand Dexterity (BHD) of school-going children of various exposed and background areas of Kanpur.

4. There will be no significant difference between the mean values of Intelligence Quotient (IQ) of school-going children of various exposed and background areas of Kanpur.

5. There will be no significant difference between the mean values of Attention (DSF) of school-going children of various exposed and background areas of Kanpur.

6. There will be no significant difference between the mean values of Executive Function (DSB) of school-going children of various exposed and background areas of Kanpur.

7. There will be no significant difference between the mean values of Vocabulary of school-going children of various exposed and background areas of Kanpur.

8. There will be no significant difference between the mean values of Visuo-spatial Ability (BD) of school-going children of various exposed and background areas of Kanpur.

9. There will be no significant difference between the mean values of Immediate Recall Memory (IRM) of school-going children of various exposed and background areas of Kanpur.

10. There will be no significant difference between the mean values of

Delayed Recall Memory (DRM) of school-going children of various exposed and background areas of Kanpur.

10. There will be no significant difference between the mean values of Recognition Memory (RM) of school-going children of various exposed and background areas of Kanpur.

11. There will be no significant difference between the mean values of Processing Speed and Accuracy (PSA) of school-going children of various exposed and background areas of Kanpur.

Further to test these hypotheses, statistical method; Analysis of Variance (ANOVA) was applied on the data collected.

Chapter-2

METHODOLOGY

2.1. Research Design

The present research work was planned as an ex-post-facto cum field study. The neuropsychological effects of an already occurred independent variable i.e., ambient air pollution on infants and children were studied. These field studies include primarily ex-post-facto scientific enquiries aimed at discovering the relation and interactions among sociological, psychological and educational variables in real social structure.

2.2. Variables

1. Independent Variable: Exposure to Ambient Air Pollution (AAP)

   Four levels of exposure to AAP were considered; high, moderate, low and negligible/ no exposure.

2. Dependent Variable: Neuropsychological Development of Infants, Preschoolers and School-going Children

3. Intervening variables (Confounding Factors) : Age, gender/sex, SES, Diet, Family size and duration of exposure.

   The potential of confounding was reduced to minimum by selecting the sample from lower socio-economic group and government aided schools (Kuppuswamy, 2017).

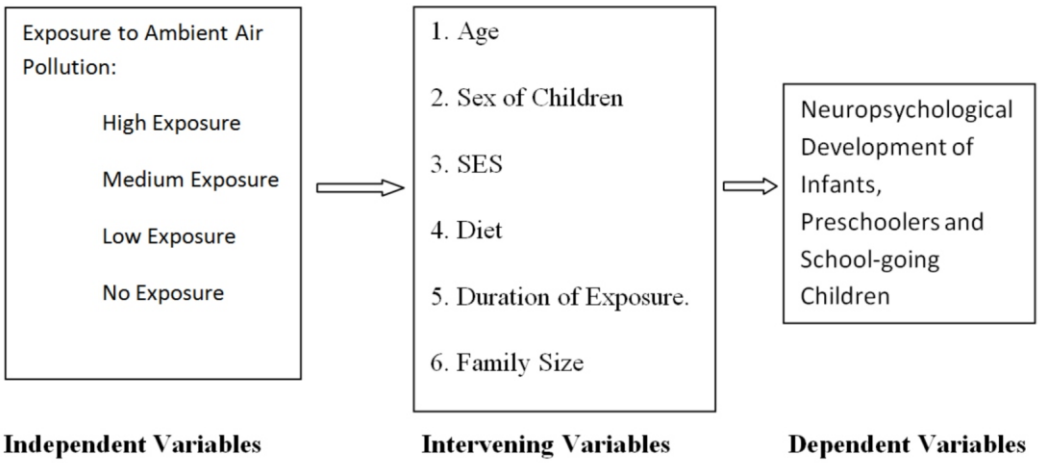


Fig. 2.1. Variables of the study

2.3. Locale of the study

Kanpur, one of the most polluted cities of the world was selected as the locale for the study. Kanpur is not only an industrial and commercial city but also densely populated with an approximate population of 4.58 million as per the 2011 census (censusindia.gov.in).

The Uttar Pradesh Pollution Control Board (UPPCB) has been monitoring Ambient Air Quality of eight areas of the city. The average Ambient Air Quality (AAQ) data; mainly the Particulate Matter (PM_{10}) for the last three years (2011- 2013) of eight areas were noted from the Kanpur office of UP Pollution Control Board.

All the eight areas were explored for various sources of air pollution in those areas. On the basis of various reports, source apportionment studies of the city by IIT, Kanpur & CPCB and personal visits of the researcher, the city was divided into four areas viz. HPA, MPA, LPA and BA for the study as given below and in Table no. 2.1 and Fig. no. 2.1. Further during the course of the study (2014-2016) the updates of the AAQ data were followed to match the variations in the levels of air pollutants of various areas earmarked for the study.

1. Highly polluted area (HPA) : Ramadevi and Dadanagar areas of the city were selected as highly polluted area. Ramadevi is a commercial area with busy markets, hospitals, educational institutes, restaurants and residential colonies as well. The area is situated at the interjection of Delhi-Kolkata Highway and Delhi-Lucknow by-pass road with lots of heavy transport vehicles coming in and going out the city throughout the day. Dadanagar is an industrial area with all kinds of industries; plastic, chemicals, consumer etc. Both the areas are full of urban activities with movements of man, material and trading. The average PM_{10} data reported by UPPCB during the six years (2011-2016) was approximately four times the standard value of 60 µgm/ m^3 (i.e., 249 µgm/ m^3 and 256 µgm/ m^3). (Table no. 3.1.)

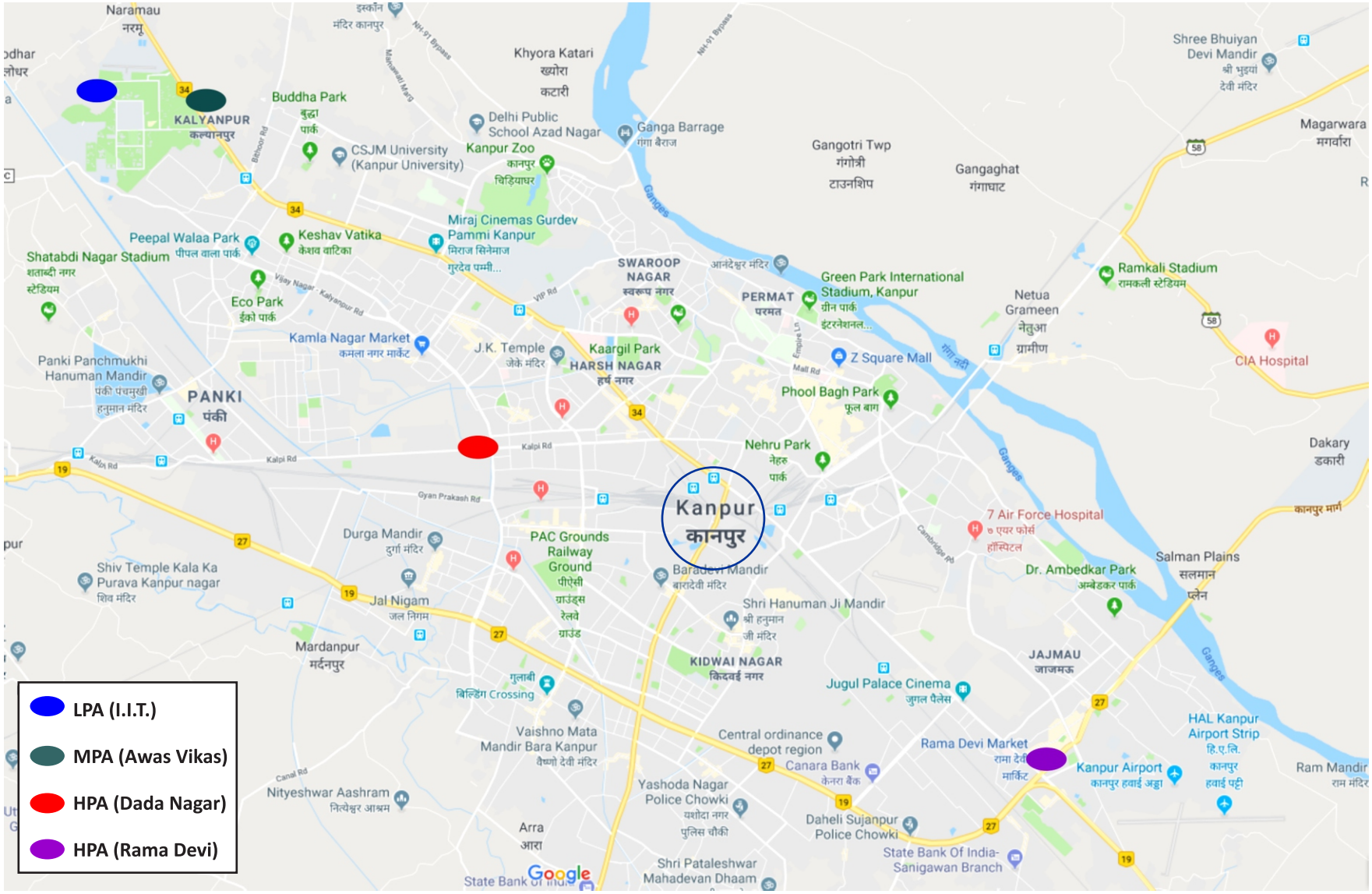
2. Moderately polluted area (MPA): Awas Vikas, Kalyanpur area was selected as moderately polluted area. The area is mainly residential and therefore not so congested with heavy vehicle traffic like highly polluted areas. A large fraction of population in these areas belongs to middle and lower income group. As the roads of these areas are connected to the highly polluted areas of Panki, Dadanagar area with road connecting GT Road to Kalpi Road, a few heavy vehicles may also be seen on these roads. The average PM_{10} data reported by UPPCB during the six years (2011-2016) was approximately three times the standard value of 60 µgm/ m^3 (i.e., 198 µgm/ m^3). (Table no. 3.1.)

3. Low polluted area (LPA): For low polluted areas, IIT campus and Naankari areas of the city were selected. Both the areas have their own developed campus/ colony. The traffic is more or less negligible as concerned to heavy automobiles and other public automobiles and the area has an open environment and greenery in the near vicinity. In one way they are the sub-urban areas of the district. However, due to the ongoing construction activities, the particulate (PM10) concentration of the area was reported to be increased during the last few years from 70 to 130 approximately. The average PM_{10} data reported by UPPCB during the six years (2011-2016) was approximately two times the standard value of 60 µgm/ m^3 (i.e., 134 µgm/ m^3). (Table no. 3.1.)

4. Background area (BA): The Sarsaul area situated on the outskirts of the city was selected as the background or unexposed area. The area is mainly surrounded by greenery. Houses are situated in the interiors of the area away from the main road. LPG is mainly used for cooking in houses. The roads have almost negligible pollution. Internal transportation is not needed to move around in the area, if needed they have either bicycles or bullock-carts for carrying agriculture related goods. To reach the main city few families have motorcycles or they may get public transportation from the main road which is also not very frequent. There are no industries in the nearby areas. There is a government Navodaya Vidyala/ school which was established in the Sarsaul area due to the pollution free environment of the area. The area is not regularly monitored for air quality by the pollution control board. However, the National Authority of India had assessed the air quality of the area in relation with the upgradation of NH-2 (the road towards Allahabad) during the period 2013-2016. The average PM_{10} values were found to be within the NAQ Standards (NHAI, Final EIA Report, January 2016). The sample selected from these areas was considered as the control group.

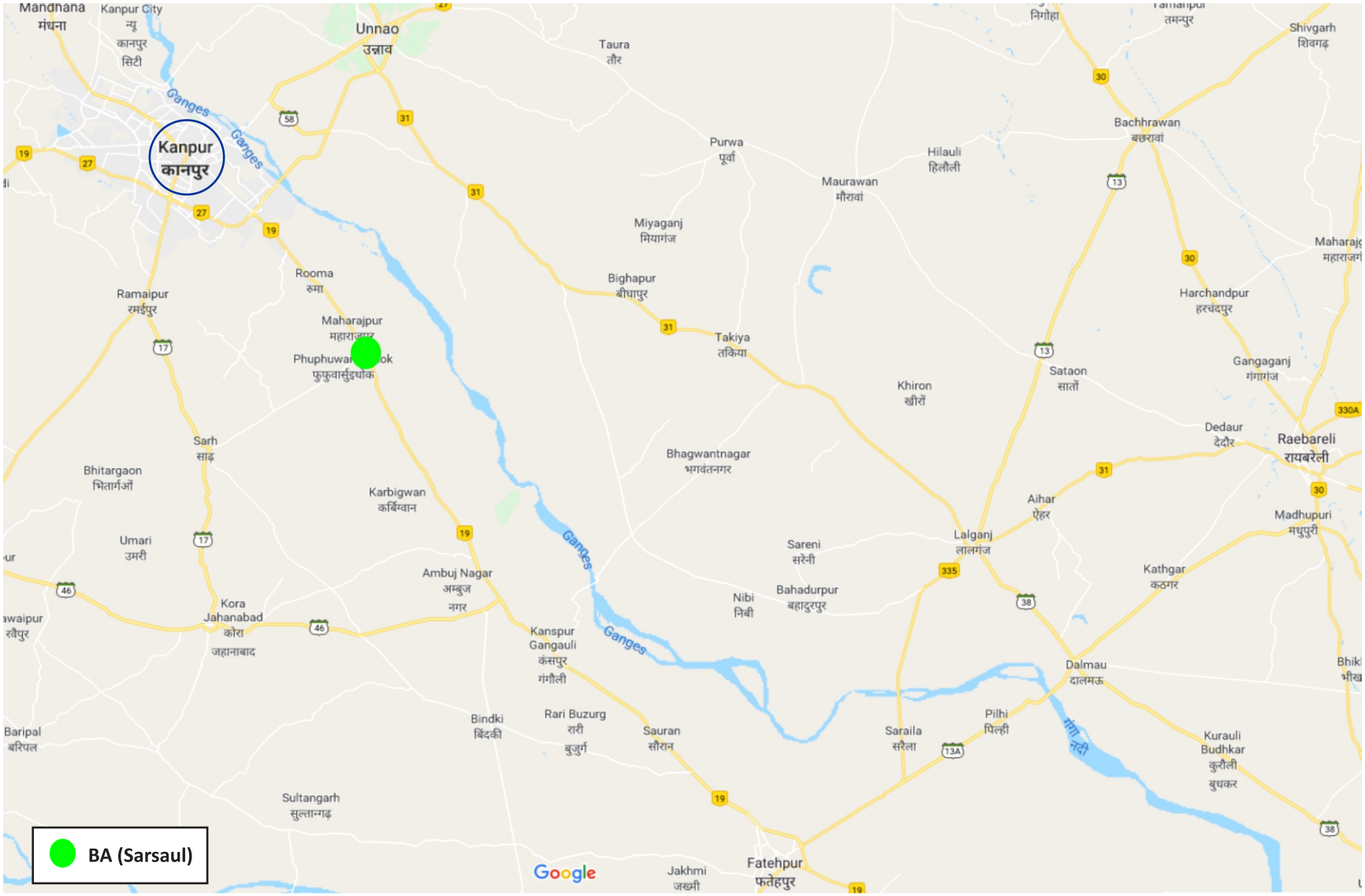
Table No.2.1 : Brief Description of Sampling Areas:

S.No.	Sampling Area	Description of the Area	Types of sources of air pollution based on land use
1.	Background Area (BA) or unexposed area	Area having minimum or least pollution	Domestic cooking, light vehicles
2.	Low Polluted Area (LPA)	Residential/ Low Traffic Area	Domestic cooking, Diesel Generators, vehicles, road dust, garbage burning
3.	Moderately Polluted Area (MPA)	Residential/ Moderate Traffic Area	Domestic cooking, Diesel Generators, vehicles, road dust, garbage burning, restaurants
4.	Highly Polluted Area (HPA)	Highly Commercial High Traffic and Industrial Area	Industries, domestic cooking, Diesel Gen., large and small vehicles, road dust, garbage burning, restaurants



Source : Google Maps

Fig. 2.2.a Location of exposed areas



Source : Google Maps

Fig. 2.2.b Location of background/unexposed areas

2.4. Sample and Method of Sampling:

The study was conducted on a sample of 740 children of various age groups; 100 infants (0-2years), 320 preschoolers (2-6years) and 320 school-going children (6-12years). The sample was selected using the method of purposive cum random sampling.

As the present research involves testing of human samples, Ethics Committee Approval from a DCGI registered 'ethics committee' of the city i.e., 'Kanpur Medical Ethics Committee' was obtained for testing the infants and children of the city

After finalizing the four areas; HPA, MPA, LPA, BA, details of the households in the area within one kilometer of aerial distance from the AAQ Monitoring Stations of UPPCB were collected from the Kanpur Nagar Nigam Office. With the help of resource persons from Anganwadi Centres, Health Centres and Government Primary Schools of the areas, the parents of infants and children were contacted at their respective houses. Informed consent was obtained from the parents in written. The school going children were mainly selected from the government schools of the four areas (within one square kilometer of the AAQ Monitoring Stations). Children of the mothers residing since five years or more in the areas earmarked were selected for the study. Other major exclusion criteria for selection of sample were:

i. Children born after any complications of delivery,

ii. Pre-term born or premature infants/ children,

iii. Children born to mothers smoking, consuming alcoholic beverages, unusual amounts of meat, fish, chicken or chalk/ mud during pregnancy,

iv. Children with mental or physical disability or anticipated genetic complications / genetic deformities.

v. Children from families having any history of diseases or allergies given in the schedule,

vi. Children not vaccinated as per their vaccination chart.

The screening of samples was done using the interview schedule prepared by the researcher (mentioned below in 'tools for data collection'). In this manner 25 infants, 80 preschoolers and 80 school-going children were selected from each of the four areas i.e., total 100 infants, 320 preschoolers and 320 school-going children.

Table No. 2.2 Constitution of the Sample (N=740)

	Infants (0-2yrs.) (N=100)			**Preschoolers (3-6yrs.) (N=320)**			**School-going (7-12yrs.) (N=320)**		
Areas	**Girls**	**Boys**	**Total**	**Girls**	**Boys**	**Total**	**Girls**	**Boys**	**Total**
HPA(N=185)	15	10	**25**	42	38	**80**	32	48	**80**
MPA(N=185)	10	15	**25**	40	40	**80**	50	30	**80**
LPA(N=185)	9	16	**25**	50	30	**80**	36	44	**80**
BA(N=185)	17	8	**25**	40	40	**80**	44	36	**80**
Total (N=740)	51	49	100	172	148	320	162	158	320

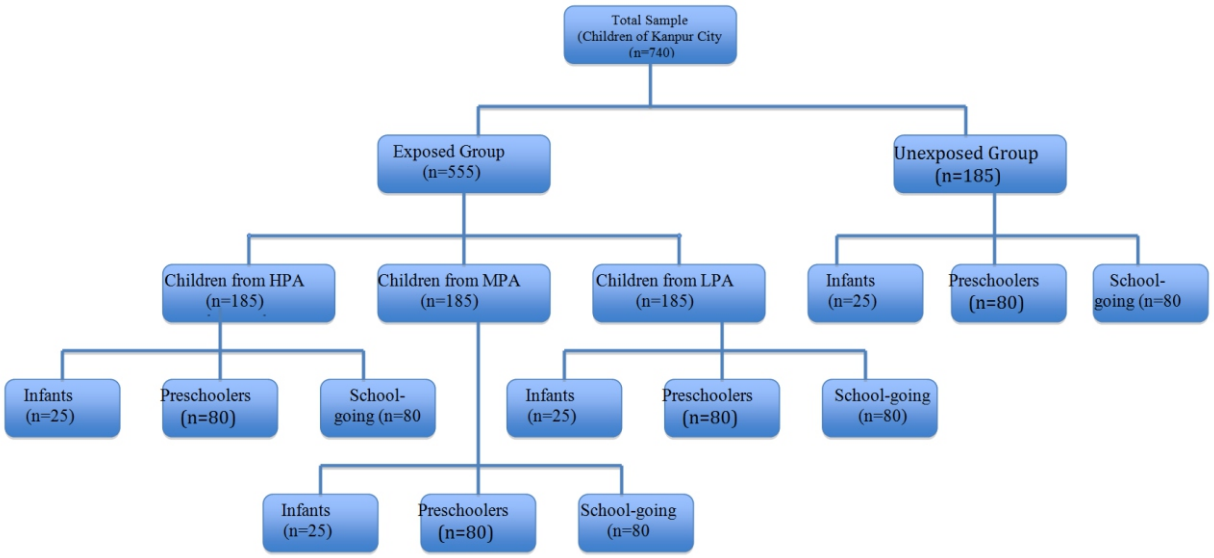


Figure. No. 2.3 Constitution of the sample

2.5. Tools used in data collection

A. Exposure Assessment:

Ambient Air Quality (AAQ) monitoring carried out for 24 hours with a frequency of twice a week from various UPPCB monitoring sites were used to study the air pollution exposure on infants and children residing in the three exposed areas. The average PM_{10} data of six years (2011-2016) of the three areas (HPA, MPA & LPA) was considered for the study.

The aerial distance from the AAQ monitoring station was measured on the geographical map on Google. Households and primary schools within one square kilometer grid area from the AAQ monitoring station were approached for selection of children for the study.

Personal activity pattern of mothers during pregnancy, three years before pregnancy, at present and of children was enquired about using an interview schedule (Annex.III). They were asked about how much time they spent outside and how much time they stayed inside daily on an average.

B. Background Information of the Children:

An interview schedule (Annex.III) constructed by the researcher was used to collect the following information about the subjects:

(a) Personal data: regarding age, duration of residence in the area, monthly income of family, occupation of parents, number of family members.

(b) Clinical examination was also included in this section to study the general health of the subject.

(c) Subjective symptoms: regarding various organic physiological disorders related to vehicular pollution like headache, blurred vision, dizziness, respiratory disease etc.

(d) Anthropometric Measurements: Height, weight, mid upper arm circumference, chest circumference and head circumference of children were measured for general health assessment.

(d) Dietary Survey: The children were asked about their general diet pattern throughout the day. 24 hours recall method was used for dietary survey. The mothers and children were enquired about what the infants and children had in their meals; early morning, breakfast, tiffin, lunch, tea time, dinner and bed time usually in a day and in how much quantity.

In case of infants, mothers were asked whether breast feeding done or not, till what age child was breast fed, first milk colostrum was given or not, age of starting top milk, type of milk given and the age of weaning.

(e) Other Lifestyle Factors: Any family member has a habit of smoking including the mother herself, Mode of cooking: LPG, kerosene stove or chulha using fossil fuel; Source of drinking water: handpump, municipality supply, water filters or Reverse Osmosis (RO).

(f) Prenatal History: As the effect of exposure to air pollution on children during prenatal development was also being studied, the mothers were enquired about the prenatal history and the birth details of the child. The prenatal history included items like any kind of X-ray or medication the mother had gone through during pregnancy, intake of fish (source of toxic metal magnesium) or chalk/ mud due to pica habit, kind of work; light, heavy or normal including duration they were involved in during pregnancy.

(g) Birth Details: It included method of delivery of the infant/ child: normal or caesarian, Birth place: hospital or home, Delivery time: full time or pre-term, maternal age at birth, Birth weight and Birth order of the child.

Socio-economic Status (SES):

Socio economic status (SES) refers to an individual's position within a hierarchical social structure, which is one of the important determinants of health status (Singh, Tulika etal, 2017). After collection of the family details related to education and occupation of the family, the modified Kuppuswamy's scale (Singh, Tulika etal, 2017) was used to analyse the socio-economic status of the families. The modified Kuppuswamy scale is commonly used to measure SES in urban and peri-urban communities. The Kuppuswamy scale was devised by Kuppuswamy in 1976 and has been revised thrice. This is the fourth version of the scale which was revised in 2017 using the latest Consumer Price Index (CPI) for industrial workers. The scale is based on a composite score considering the education and occupation of the head of the family along with monthly income of the family, which yields a score of 3-29. This scale classifies the study population into five socio-economic classes; upper, upper middle, lower middle, upper lower and lower (Annexure no.IV).

C. Neuropsychologial Assessment of Children:

In our study three different age groups (0-2, 3-6, 7-12 years) are being studied using culturally relevant tests (Indian Adaptations); both IQ and domain specific tests. The performance of exposed group of children on these tests was compared to the performance of a background group of children from clean area on these tests. This strategy shall allow testing exposure-outcome relationships with certain key tasks at widely divergent ages.

Three types of neuropsychological assessments were executed in the present study for the three age groups of children:

1. Evaluation of Motor and Mental Developmental Quotients (for 0-2 years):

For age 0–2 years, the motor and mental developmental quotients, considered equivalent to the Intelligence Quotient were measured to assess the brain functioning as affected by AAP.

Another important aspect in studying young children is consideration of cultural or regional variations. Developmental Assessment Scale for Indian Infants (DASII) the Indian Adaptation of Bayley's Scale of Infant Development (BSID), developed by Dr. Pramila Pathak, a test very popular in assessing the development of infants in Indian culture has been used in the following study for the subtle neuropsychological changes in infants (0-2years) due to the exposure to toxic ambient air pollutants.

DASII by Dr. Pramila Pathak, the Indian Adaptation of BSID:

The scale consists of 67 items for motor development and 163 items for mental development. The motor development items cover the child's development from supine to erect posture, basic locomotive skills like walking, climbing, jumping, skipping etc. The mental development items record the child's cognizance of objects in the surroundings, perceptual pursuit of moving objects, exploring them to meaningful manipulation, development of communication and language comprehension etc. The total 230 items simultaneously and independently evaluate the two basic aspects of development i.e., motor and mental performances. The reliability of test used is 0.88 for motor scale and 0.91 for mental scale (Pathak, 1997). The norms of the test have been developed using age placements at 50% pass level for various items. For assessment of a child's motor and mental development, initially the obtained raw scores of a child were converted into motor age and mental age as per the norms given in the test manual. The motor age and mental age were further used for calculating Motor and Mental Development Quotients (DMoQ & DMeQ) respectively by comparing them with child's chronological age and multiplying it by 100. The performance of the child was assessed on the basis of obtained DMoQ and DMeQ values on motor and mental scales. DMoQ and DMeQ values of less than the standard value of 100 were considered as lower mental performance.on the motor and mental scales respectively. DMoQ and DMeQ values more than 100 were considered as 'higher performance'.

2. Evaluation of Intelligence Quotient in combination with other domains of neuropsychological development (for 2-6 years):

The approach of measuring full IQ in combination with various domains of neuropsychology was used for preschoolers.

The Stanford Binet Scale Indian Adaptation by Kulshreshtha, popularly used in Government Regional Psychological Centres and some private counseling centres for child guidance and counselling was used to study the full IQ and six sub-divisions of intelligence; visual perception, motor co-ordination, language development, immediate memory, concept formation, reasoning of preschool children.

Indian Adaptation of Stanford Binet Intelligence Scale by Kulshreshtha:

Indian Adaptation of Stanford Binet Intelligence Scale by Kulshreshtha (Third Revision, Form L-M) is one of the commonly used tests for measuring intelligence of children above two years of age in India. The test is a standardized test with high reliability and validity (Terman, L.M. and Merrill, M.A., 1960). The hindi adaptation of the test was used keeping in view of the cultural variation different from America. Moreover, the test items are incorporated accepting the fact that the pattern of growth and development of intelligence with growing age shows the same trends in all the countries.

The test includes items related to visual perception, motor co-ordination, language development, immediate memory, concept formation and reasoning as per the age levels. There are twelve items for age levels two to four years and six items for age level five to adult level. Separate alternative items are given for each age level. The mental age or IQ is measured by assessing the overall performance of the child on these items given for various age levels.

After identification of basal age and ceiling age of the child as per the items successfully attempted by the child, mental age was computed according to the total credits given. Through computation of mental age and chronological age, full IQ was calculated. As per the norms of intelligence in the test manual, IQ value in the range of 90 to 110 was considered as an average intelligence. Thus, the IQ value of less than the 90 was considered as below average intelligence.

Separate scores for each category of neuropsychological assessment were given on the record sheet (Annexure no.). Scores for each category were

calculated by dividing the total number of correct items by the total number of items attempted by the preschooler upto his/ her chronological age. A score of '1' was considered as 'at par' performance, a score less than '1' was considered as 'lower' performance, and a score more than '1' was considered as 'higher' performance

3. Evaluation of Domain Specific Neuropsychological Functions (for 6-12 years) :

For 6-12 years age group of children, the strategy used in neuropsychological assessment was incorporation of various domain specific psychological tests. For the selection of various domain specific tests, the literature pertaining to use of various test batteries in neurobehavioural toxicology was studied extensively. As per the age group, various short tests like Block Design Test (Part of Malin's Test), Trail Making Test, Digit Span Memory Test, and Speed and Accuracy Tests were administered on few school going children (6-12 years) of nearby areas to check the feasibility of the tests.

Thereafter, on the basis of understanding of various concepts by the children and ease of administration on the children, acceptability to the children, the standardized tests given in the table 2.3 were finalized for the school going children on the guidelines similar to other test batteries used to assess the neuropsychological effects of various environmental toxins like the air pollutants (White, R.F. etal, 2009).

All the tests were short tests, consuming very less time and were used in a specific sequence in form of a test battery. The cognitive functions measured using various tests are being described briefly:

Full Intelligence Quotient/ General Intelligence:

The general intelligence or full IQ of a school-going child was measured using the Developmental Screening Test (DST) by J. Bharat Raj, a checklist having certain items/tasks to be ticked as per the age group. It is a standardized test with a test-retest reliability of 0.98 and high validity, as revealed by a strong correlation coefficient of 0.85 and 0.75 with Seguin form board and Columbia mental maturity scale respectively.

Attention/ Concentration:

Attention or concentration an important aspect of school-going children's performance was measured using digit span forward (DSF) sub-test of Malin'test. The testing was started with two numbers. The task was to repeat

Table no. 2.3. List of various standardized tests used for measuring various neuropsychological variables (DV) of infants, preschoolers and school-going children in the study

S.No.	Age Group	Neuropsychological Measure (Dependent Variable) studied	Tests used to study the variable
1.	Infant (0-2 years)	Motor and Mental Development Quotient (DMoQ & DMeQ)	Indian Adaptation of Bayley's Scale for Infant Development (BSID): Developmental Assessment Scale for Indian Infants (DASII) by Dr. Pramila Pathak
2.	Preschoolers (3-6 years)	Full IQ, visual perception, motor co-ordination, language development, immediate memory, concept formation and reasoning	Indian Adaptation of Stanford Binet (SB) Test by Kulshreshtha
3.	School-going children (7-12 years)	Full Intelligence Quotient/ General Intelligence	Developmental Screening Test (DST) by Bharat Raj (A checklist)
		Attention	Digit Span Forward (A part of Malin's Test)
		Executive Function	Digit Span Backward (A part of Malin's Test)
		Language (Verbal skills)	Vocabulary (A part of Stanford Binet Test)
		Visuospatial ability	Block Design (A part of Malin's Test)
		Learning & Memory	· Delayed Recall · Immediate Recall Memory · Recognition Memory (All were part of PGI Memory Test)
		Perceptual Accuracy	Coding (A part of Malin's Test)
		Finger Dexterity (Motor)	Pins & Board Test

the numbers in same sequence as presented. The highest number of digits repeated in the same manner without error was considered as the score of the child. The range of scores was a minimum of 2 to a maximum of 9.

Executive Function/ Working Memory:

The capacity to learn and manipulate stimuli i.e., the working memory also known as executive function was measured using digit span backward (DSB) sub-test of Malin'test. The test was started with two digits. The task was to repeat the numbers in reverse manner as presented. The highest number of digits repeated in the reverse manner without error was considered as the score of the child. The range of scores was a minimum of 2 to a maximum of 8.

Verbal Sills/ Vocabulary:

Understanding of the vocabulary of the local language hindi was used to assess the verbal skills. Vocabulary test; a part of Stanford Binet's Test (SB Test) by Kulshreshtha was applied. The test consists of forty five words in increasing order of difficulty. The child was asked to define the words from the list one by one. One mark was given for each correct meaning. There was no negative marking. On failure to define six consecutive words from the list, the test was discontinued and the final score was given.

Visuospatial Ability:

Block Design (A part of Malin's Test) was used to measure the visuospatial ability of children that require simple mental manipulation of spatial information. Children were asked to put together red and white blocks as per the design displayed in various cards. Initially, simple designs of four blocks and later on designs of nine blocks were displayed. Time taken for completion of each design was noted. Credit points for each design completed were given as per the time taken as given in manual.

Learning and Memory:

The ability to perceive information given, to retain it and to reproduce it i.e., the ability to learn and memorize was assessed using PGI memory scale often used with neurotic and psychotic patients. The test-retest reliability of the test ranged between 0.70 and 0.84 (Pershad, 1977; Pershad and Wig, 1978). Delayed recall, immediate recall and recognition memory sub-tests of the PGI memory scales were used.

a) In case of delayed recall, five words were read one by one by the researcher with a pause of one second in between. The task for the

child was to hear the words attentively and recall the words after one minute. A score of one was given to each word recalled correctly. The maximum score given was ten for two sets of five words each.

b) In case of immediate recall, three sentences having three, four and five clauses were read one by one before the child. The task for the child was to hear the sentences attentively and recall them after a second. A score of one was given to each clause reproduced correctly. The maximum score given was twelve.

c) For recognition memory, the child was shown a card of ten pictures for thirty seconds. After two seconds another card having eighteen pictures was shown. The task for the child was to recognize the objects in the second card which he/ she had previously seen in the first card. One mark for each correct answer was given. Thus, a maximum score of ten could be given.

Vigilance/ Perceptual Accuracy/ Coding:

A sub-test of Malin's test; 'coding' was also used to evaluate the perceptual accuracy of the school-going children.

Different shapes like stars, square, circle, triangle etc. were given in five rows of ten shapes in each row. The task for children below 8 years was to form lines; horizontal, vertical, double etc. inside the shapes using pencils as per the sample given in the first row within 2 minutes time. First five shapes were to be filled by the instructor as example. One point for each correct code was given. Bonus points ranging one to five were given for speed as per the manual. Thus, a maximum of fifty score (45+5) could be given.

For children 8 years and onwards, symbol codes were given for numbers 1 to 9 as sample. The task for the child was to mark the symbol codes for numbers given in four rows of twenty five numbers (1 to 9) in each row. First seven shapes were to be filled by the instructor as example.

One point for each correct code was given. Thus, a maximum of ninety three score could be given.

The Malin's Test was found to be highly reliable and valid test. The reliability coefficient of Malin's test, measured through test-retest method was 0.91. And the congruent validity coefficient obtained was 0.63 as mentioned in the test manual.

The developmental tasks performed by the child were mainly ticked after asking the mothers and observing the child as and when required.

Accordingly, the mental age of the child was calculated. Further using the mental age and chronological age, the full IQ of the child was computed.

Finger Dexterity (motor skills):

Manual Dexterity i.e., the ability to make coordinated hand and finger movements to grasp and manipulate things develops during early childhood (2-6years). It includes muscular, skeletal and neurological functions to produce small and precise movements. Manual dexterity follows the set pattern of development i.e., from gross motor development to fine motor development. Till the age of two years, the gross motor functions of hands and legs develop very well. The use of finer muscles of fingers develop later on as manifested through development of basic hand skills like holding a pencil, cup, spoon etc. after 1-2years of age. Thus, manual dexterity becomes an important aspect of neuropsychological behavior. In our study Finger Dexterity of preschoolers was assessed using Pins and Board Test.

Pins and Board test was used to measure the finger dexterity of 6-12 year old children. The equipment consists of a rectangular wooden board with hundred holes in ten rows of ten holes each. The task is to insert the pins into the holes in two trials of 60 seconds. In this manner three form of scores were obtained; number of pins inserted with preferred hand (towards right) in 60 seconds i.e., RHD, number of pins inserted with non-preferred hand in 60 seconds (towards left) i.e., LHD and number of pins inserted with both the hand (towards the centre) in 60 seconds i.e., BHD.

2.6. Data Collection

After the ethics committee approval and informed consent, the mothers and their children were contacted in their respective houses. After building a rapport with the mothers, personal information like education, occupation of parents and family income etc..was collected from them using an interview schedule prepared by the researcher. The mothers were also enquired about the details of delivery of the child and characteristics of the child at the time of birth. The neuropsychological tests were applied on the children as per the age group in a definite sequence, in a room with minimum distractions.

In case of infants, special care was taken during administration of the test. DASII test was applied on infants in presence of their mothers in a quiet room with least distractions. Each child's behaviour was observed very closely. His/ her interest in certain materials being used and the mood of the child were especially taken care of. Motor and mental development scale

items were administered simultaneously to avoid repetition of certain items and to make the test less exhaustive for the child. On an average the time taken for testing an infant above 10 months was one and a half to two hours. Younger infants took lesser time as they could not perform the items after younger age levels.

On completion of the test, a small toy/ reward was given to each child as per the age group.

2.7 Observations of the researcher during data collection:

During the process of data collection, while interviewing the parents, the researcher noted certain important observations regarding the ambience of the city and its adaptation by the people for living in the existing environment of the city.

The polluted air of the city could be sensed by the residents of the city outside their houses, on roads and streets. However, the sensitivity was found to be more among the new residents of the city.

Slow moving cars and other vehicles was a common scene of the city. During the traffic jam standing in the long queues of vehicles, irritation in eyes, dizziness and headache were some of the common symptoms reported by general public and the researcher herself.

Demolition and construction work going on in many areas, burning of garbage in the streets were some of the common observations during the research period.

The situation was same throughout the year. During the summer season, the dry air and wind could easily carry out the dust having particulate matter and carbon particles/ soot to distant places. During the winter season, due to an increase in humidity and smog the air particulates could be sensed by heaviness in the atmosphere leading to congestion, cough and cold.

In industrial areas, the suffocation and odour of various chemicals from the factories like plastic, leather footwear etc. could be felt heavily in the damp and low roof dwellings of the residents either alloted by the government or by the factory administration in the factory campus or nearby areas. In most of the families, apart from the main member working in the factory, the other family members including old ladies, housewives and children were also engaged in some or the other tasks of the factories like making straps of slippers, packaging goods & materials, stitching bags for the factory to earn some extra income. The people in those colonies had become

accustomed to living in the suffocated smelly quarters, working with chemically treated items of various industries.

Such kind of environmental stress and suffocation in the air could appear to be very normal for the local public including children and old age people but, it could drain children's physical and mental resources & ultimately affect their performance. A study on the air quality of a school by Raw etal, (1990) revealed that when individuals/staff experienced just two symptoms of discomfort, they began to perceive a reduction in their own performance. It can thus be assumed from the above observations that when large number of people, children and old age people experience such signs of discomfort related to the air outside their houses and schools, mental and motor performance of people, teaching & learning performance of children would degrade over time.

2.8 Analysis of the data collected

After collection of the data, the data was statistically analysed to get the results and make inferences. All the statistical analysis was done by the researcher through the SPSS software. The major statistical methods used for the analysis (Fig. no. 2.4) are being discussed below.

The mean of scores on various neuropsychological tests was worked out for three different pollution level exposed groups (LPA, MPA, HPA) and one background group (BA).

To test the hypothesis formulated that whether there is a significant difference between the means scores on various neuropsychological tests of the three pollution exposed groups and one background group or not, one way-ANOVA (Analysis of Variance) test was worked out. Further, to see which of the three exposed groups differ significantly from the control group, prevalence of lower performance on various psychological tests of children of the three exposed groups was compared with that of the control group using chi-square and odds ratio calculations.

Relationship of the dependent variable (the scores on various neuropsychological tests here) with the intervening variables of age, gender, SES and family size was evaluated using the correlation method of analysis.

In case of significant correlation with the intervening variables, the confounding effect of these independent/ predictor variables on various dependent/ criterion variables was calculated using multiple regression analysis.

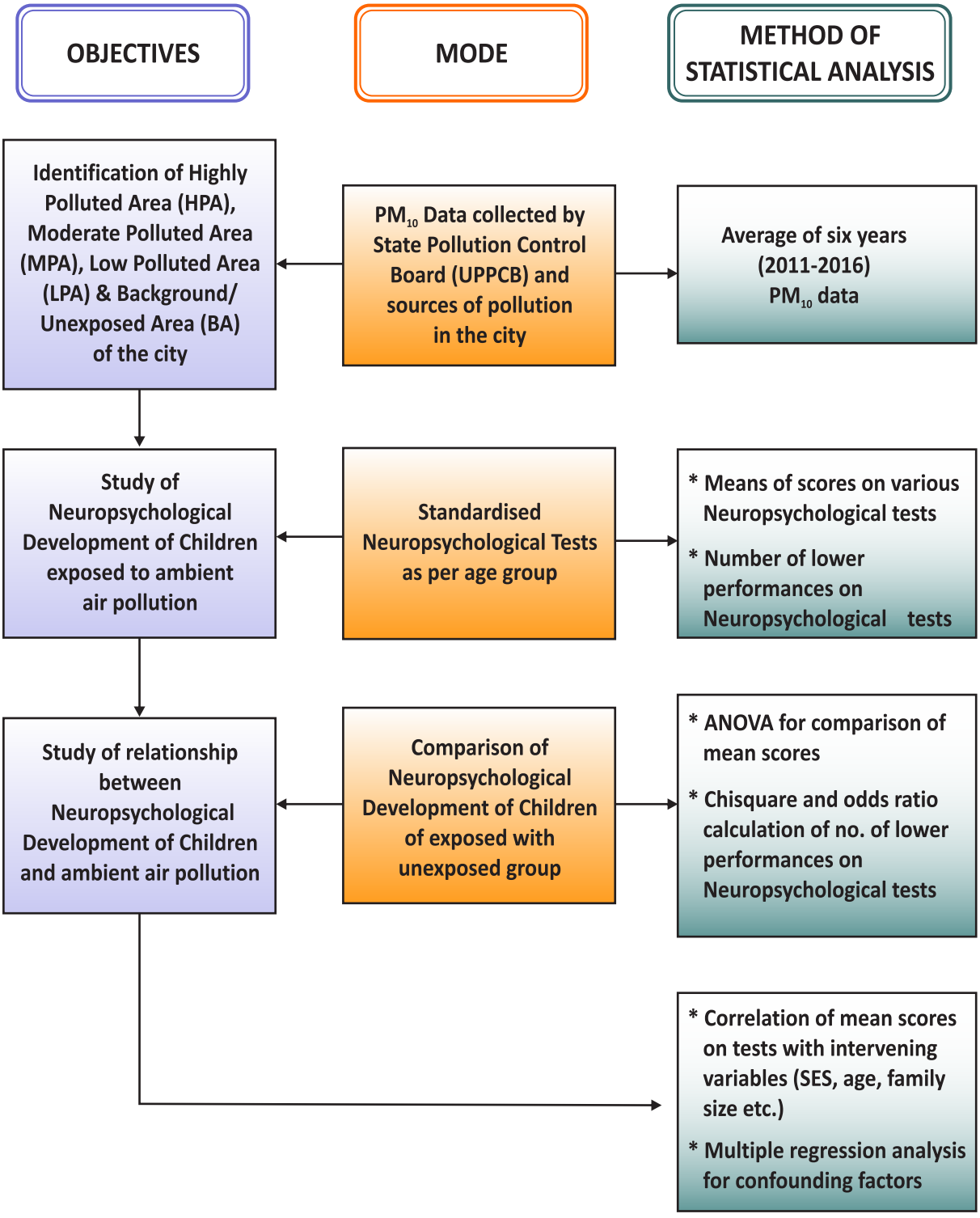

OBJECTIVES
MODE
METHOD OF STATISTICAL ANALYSIS
Identification of Highly Polluted Area (HPA), Moderate Polluted Area (MPA), Low Polluted Area (LPA) & Background/ Unexposed Area (BA) of the city
PM10 Data collected by State Pollution Control Board (UPPCB) and sources of pollution in the city
Average of six years (2011-2016) PM10 data
Study of Neuropsychological Development of Children exposed to ambient air pollution
Standardised Neuropsychological Tests as per age group
* Means of scores on various Neuropsychological tests
* Number of lower performances on Neuropsychological tests
Study of relationship between Neuropsychological Development of Children and ambient air pollution
Comparison of Neuropsychological Development of Children of exposed with unexposed group
* ANOVA for comparison of mean scores
* Chisquare and odds ratio calculation of no. of lower performances on Neuropsychological tests
* Correlation of mean scores on tests with intervening variables (SES, age, family size etc.)
* Multiple regression analysis for confounding factors

Fig. 2.4. Research Module of the Study

2.9. Counselling of Parents and Recommendations:

After the assessment of neuropsychological development of infants and children of exposed and unexposed areas, the parents of infants and children and the general public of various study areas were made aware of the subclinical effects of ambient air pollution on the mental and motor development of their children. The parents were made aware of the normal pattern of growth and development of infants and children of the age group 0-12 years. The parents were counselled about what measures and precautions could be taken to reduce ambient air pollution and to facilitate the proper development of their children. The parents as well as teachers of primary government schools were informed about various activities the infants and children could be engaged in for proper neuropsychological (cognitive and motor both) as per their age groups. The parents were counseled through personal visits at their respective houses and by organizing group discussions, workshops on related topics in some common places like anganwadi centres, primary schools.

On the basis of the results obtained necessary recommendations were made for the researchers for further research in the field, policy makers and town planners regarding the slow and deleterious effects of ambient air pollution on our infants and children. Measures and steps which could be taken by the government and non-government institutions to make the environment healthy and safe for the children and to reduce the air pollution to the minimum were suggested.

Chapter-3

RESULTS AND DISCUSSION

The results of the study are being presented under following heads:

3.1. Ambient Air Quality of the Areas earmarked for the Study

3.2. Neuropsychological Development of Infants and Children of the Exposed and Background areas of Kanpur city

3.1. Ambient Air Quality of the Areas earmarked for the Study:

The first objective of the present study was to collect the baseline information regarding ambient air quality of Kanpur. Exposure assessment is the initial step of assessment of health risks associated with air pollution (USEPA) and one of the most commonly used approach for measuring exposure is environmental monitoring (WHO, 2001). The method of environmental monitoring takes into consideration all the fluctuating environmental factors like humidity, temperature, wind speed and direction etc. Environmental monitoring has often been used for exposure assessment in studies on the effect of neurotoxicity of ambient air pollutants on humans (Ryan et al, 2007, 2008; Harris, M.H. etal, 2015; Takashi Yorifuji et al. 2016). Interview or questionnaire is other most commonly used method of exposure assessment in epidemiological studies. Information on both past and present exposures of industrial or occupational settings can be obtained through these methods. However, it is a subjective approach which relies heavily on the recall of the subjects under study. There may be chances of over-reporting in case of exposed subjects and under-reporting in case of control group.

Apart from environmental monitoring, the other objective approach for exposure assessment is biological monitoring which involves the measurement of chemicals or their metabolites in exposed individuals. Biological monitoring reflects present day, ongoing exposures which are insufficient to construct an integrated measure of exposure overtime. In addition as internal levels of exposure to a neurotoxicant cannot be measured in the target tissue in humans, measurements in other biological

tissues like blood, urine or hair are typically used to get the estimates of the exposure (WHO, 2001).

Environmental monitoring has the advantage of giving information regarding past exposures also through the data records maintained. Thus, in the present study, environmental monitoring, one of the most reliable methods of estimating the population exposure to various ambient air pollutants was used.

To assess the exposure levels of children of the city, the AAQ data monitored by the state pollution control board through its various environmental monitoring stations was used. Thus, the secondary data was collected by the researcher through the UPPCB office. According to the annual estimates of PM_{10} data, the city was divided into three levels of exposure; low pollution area (LPA) (IIT Kanpur), moderately polluted area (MPA) (Awas Vikas) and highly polluted areas (HPA) (Ramadevi, Dadanagar) as also mentioned in the chapter of methodology.

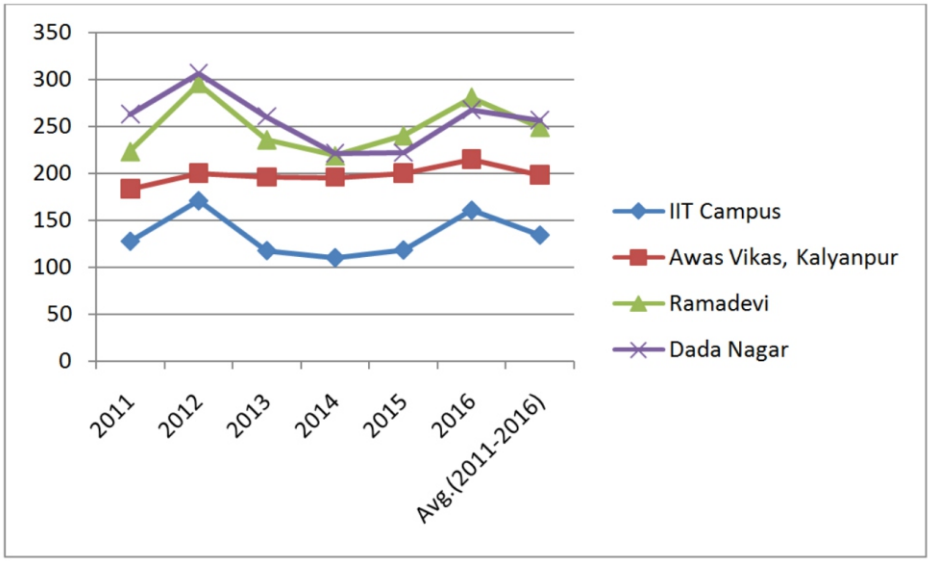
The Sarsaul area on the outskirts of the city, mostly a green area with many trees and farms, having PM_{10} values within the standard limits (NHAI, Final EIA Report, January 2016) was considered as the background area (BA) for the study.

As per the first objective of the study, the latest update of Ambient Air Quality was collected from Uttar Pradesh Pollution Control Board (UPPCB) and the variations in the level of the most significant air pollutant; PM_{10} of four exposed areas (Ramadevi, Dadanagar, Awas Vikas and IIT Kanpur) earmarked for the study were matched. The table given below (Table 3.1) shows the annual estimates of the Ambient Air Quality data of the major air pollutant i.e., PM_{10} (during the six years; 2011-2016) of the exposed areas of the city as measured by UPPCB. (Fig. 3.1)

Table No. 3.1. Average Ambient Air Quality Data of PM_{10} (in µgm/ m^3) of various exposed areas of Kanpur earmarked for the study (Year 2011-2016)

AREAS	2011	2012	2013	2014	2015	2016	Average (2011-2016)
IIT Campus (LPA)	127.8	171.2	117.8	110.2	118.4	161	134.4
Awas Vikas, Kalyanpur (MPA)	183.1	200.1	195.8	195.6	200	214.9	198.25
Ramadevi (HPA)	223.3	295.5	235.9	218.9	240.2	280.9	249.12
Dada Nagar (HPA)	263	306.5	260.7	221.4	222	267.4	256.83

Source: UPPCB



Source: UPPCB

Figure 3.1. Average Ambient Air Quality Data of PM_{10} (in µgm/ m^3) of various exposed areas of Kanpur earmarked for the study (Year 2011-2016)

The annual estimates of the Ambient Air Quality data of the major air pollutant i.e., PM_{10} (during the six years) of the four exposed areas of the city revealed that,

a. in all the four areas the recorded PM_{10} values were exceeding the standard values (60 µgm/ m^3) in three areas namely Ramadevi, Dadanagar and IITK, since year 2011 there was a decline in level of PM_{10} during the year 2014,

b. however, in all the four areas, after the year 2014, a rise in the level of PM_{10} was observed,

c. Awas Vikas Kalyanpur being a residential area had comparatively lower range of PM_{10} emitted in the air with respect to Ramadevi, the commercial area and Dadanagar, the industrial area,

d. the average of six year (2011-2016) data reveals that, the value of PM_{10} was least in case of IIT (approximately twice the standard value of 60 µgm/ m^3), in higher range in the Awas Vikas Kalyanpur area (approximately thrice the standard value of 60 µgm/ m^3) and in the highest range in the other two areas namely Ramadevi, Dadanagar (approximately four times the standard value of 60 µgm/ m^3).

3.2. Neuropsychological Development of Infants and Children of the Exposed and Background areas of Kanpur city:

As mentioned in the chapter of methodology, after assessment of exposure levels of various areas of the city, a sample of 740 children of various age groups; 100 infants (0-2years), 320 preschoolers (3-6years) and 320 school-going children (7-12years) was selected from the three exposed areas and one background area of Kanpur. As per the second and third objectives of the study, various neuropsychological tests were administered on these children to study the impact of ambient air pollution on children. Three levels of pollution; high (HPA), moderate (MPA), low (LPA) and one background/ control group (BA) was considered.

Various aspects of neuropsychological development of children; the motor and mental performances of children not only reflect the developmental status of children but also play an important role in long term implications for educational achievement in childhood and adolescence (Deary et al, 2007; Fergusson et al, 2005), income and occupation in adulthood (Fergusson et al, 2005; Sternberg et al, 2001), psychological well being (Johnson et al, 2011) and life expectancy (Whalley and Deary, 2001).

Studies have proved that in addition to the hereditary factors, environmental chemical exposures may have long-term and irreversible impact on the cognitive (mental or motor) performances of children (Miller, GW and Jones, DP, 2013). Through systematic neuropsychological assessment techniques, the effect of environmental exposures on young children; one of the most susceptible population, can be assessed. In the present study, similar effort of studying the effect of ambient air pollution on three age groups of children; 0-2 years, 3-6 years and 7-12 years through neuropsychological testing was made.

The neuropsychological tests varied as per the age group. Therefore, the results are being presented as per the age groups; infants, preschoolers and school-going children. For all the three age groups, the results are being presented and discussed under two heads: one is the background information, comprising of the personal, social and demographic characteristics and the other is the specific information comprising of the data related to the effect of ambient air pollution on different aspects of neuropsychological development of the children.

3.2.1. Infants (0-2years) of the Exposed and Background areas of Kanpur city:

A total of number of about hundred infants; twenty five from each of the four areas; highly polluted (HPA), moderately polluted (MPA), least polluted (LPA) and background areas (BA) of the city were selected through purposive cum random sampling.

These infants and their mothers were contacted at their respective houses. After establishing a good rapport with them, the personal information and specific information were collected.

Table No. 3.2. Sample Size (0-2Years/ Infants) (N=100)

Highly polluted area (HPA)	Moderately polluted area (MPA)	Least polluted area (LPA)	Background area (BA)
25	25	25	25

3.2.1.1. General or related information:

For collection of general information of the sample an interview schedule made by the researcher was used. The interview schedule had items related to personal data, clinical examination, general diet pattern and subjective symptoms. The data was analysed using mean and percentage. SES was analysed using the modified Kuppuswamy's scale (Singh, Tulika etal, 2017) (Annexure IV).

A number of factors like parent's education level and occupation, income group of family have been found to affect the development of a child. To control the effect of these variables, the sample was drawn from the lower middle income group colonies assuming that the above mentioned factors would be almost the same for every child or there would be little variations.

Duration of exposure along with level of exposure also becomes an important factor for consideration of development of a child. As the effect of automobile pollution exposure doring prenatal exposure was also being considered on the development of infants. Infants of the mothers who have been residing for five years or more in the study area were included in the sample.

To study all the above mentioned aspects, personal data sheet of each child was filled. This personal data was analyzed in terms of percentage as shown below in the table 3.3

Table no.3.3. General Characteristics of the infants

S.No.	Personal Variable	BA	LPA	MPA	HPA	TOTAL
		N=25	N=25	N=25	N=25	N=100
	Mean (SE)					
1	Age (months)	13.6(1.2)	10 (0.9)	**15.2 (1.6)**	**12(1.04)**	**12.7(0.6)**
2	Weight (Kg)	8.8 (1.8)	7.2(0.9)	8.0(1.9)	**7.2(1.2)**	**7.8(0.2)**
3	Height (cm)	74.8(8.9)	69.3(3.6)	71.9(8.4)	**69.9(4.1)**	**71.4(0.7)**
	Frequency (Percentage)					
4	**Gender**					
	Girls	17(68)	9(36)	10(40)	15(60)	51
	Boys	8(32)	16(64)	15(60)	10(40)	49
5	**Period of Residence of mothers**					
a)	6-10 years	21(84)	21(84)	17(68)	18(72)	77
b)	More than 10 years	4 (16)	4 (16)	8(32)	7(28)	23
6	**Type of Family**					
a)	Nuclear	10(40)	6(24)	11(44)	11(44)	38
b)	Joint	15(60)	19(76)	14(56)	14(56)	62
7	**Total no. of Family Members**					
a)	3 to 4	8(32)	7(28)	8(32)	6(24)	29
b)	5to 8	15(60)	15(60)	11(44)	15(60)	56
c)	9 to 12	2 (8)	3(12)	6(24)	4 (16)	15
8	**Socio-economic Class (Kuppuswamy, 2017)**					
a)	Upper Middle	2(8)	6(24)	0	1(4)	9
b)	Lower Middle	19(76)	11(44)	21(84)	23(92)	74
c)	Upper Lower	4(16)	7(28)	4(16)	1(4)	16
d)	Lower	0	1(4)	0	0	1

Personal, social and demographic characteristics of the infants studied are shown in table no. . The mean age of infants was 12.7 months. The mean weight of infants was also found to be 7.8 Kg which was almost similar in all the pollution exposed and background areas.

Kuppuswamy SES scale **(Singh, Tulika etal, 2017)** was used for analyzing the socio-economic status of the family on the basis of education and occupation of the head of the family and the monthly income of the family (Annexure IV). As revealed in table no., overall in all the four areas, majority (74%) of the children belonged to lower middle income group families. In all the four areas individually also majority of the families belonged to the lower-middle income group. During data collection it was observed that, houses mainly had two or three rooms with proper ventilation and all the basic amenities like T.V., refrigerator, and cooking gas.

In most (62%) of the households, the families were joint families having 5 to

8 family members. None of the families had a member who was reported to be smoking inside/ outside the house in daily routine.

Mothers were also enquired about birth of the child, the details of their own feeding habits or any medication during pregnancy and the feeding habits of their child (Annexure no. III). In most of the cases it was a full term normal delivery under supervision of a registered medical practitioner in the hospital. No medication was done during pregnancy. None of the mothers reported to be consuming exceptional amount of fish or had any special craving habits like pica during pregnancy. All of them were engaged in four to five hours of household work daily during pregnancy. All infants were breastfed till one year of age and weaning was started at the age of six months on an average.

3.2.1.2. Specific Information/ Effect of ambient air pollution on different aspects of neuropsychological development of infants (0-2 years) :

After getting the mothers' consent 'Developmental Assessment Scale for Indian Infants' (DASII) by Dr. Pramila Pathak was administered on the infants and their Motor and Mental Development Quotients (DMoQ & DMeQ) were calculated.

The results in this section are being discussed under following heads:

a. Motor Development of Infants and Ambient Air Pollution

b. Mental Development of Infants and Ambient Air Pollution

3.2.1.2.a. Motor Development of Infants and Ambient Air Pollution:

After collection of data, the raw scores on the motor scale of DASII of various infants were calculated. The raw scores were then converted into motor development quotients (DMoQ) as mentioned in the test manual. The mean values of motor development quotients (DMoQ) of infants on DASII test in the four study areas are shown in the table no. 3.4.

The mean values of DMoQ of 0-2 year children of the four study areas were found to decrease with increasing pollution levels. The mean value of DMoQ was highest in case of background area (107.14) and lowest in HPA (92.58) .

Table no.3.4. .Mean values of motor development quotients (DMoQ) of the infants (0-2years) of different pollution exposed (LPA, MPA & HPA) and unexposed areas (UA).

BA		LPA		MPA		HPA		Total	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
107.14	2.48	95.72	2.43	93.70	2.93	92.58	1.89	97.29	1.34

To test whether the difference between these mean values of DMoQ was significant or not, ANOVA test was applied.

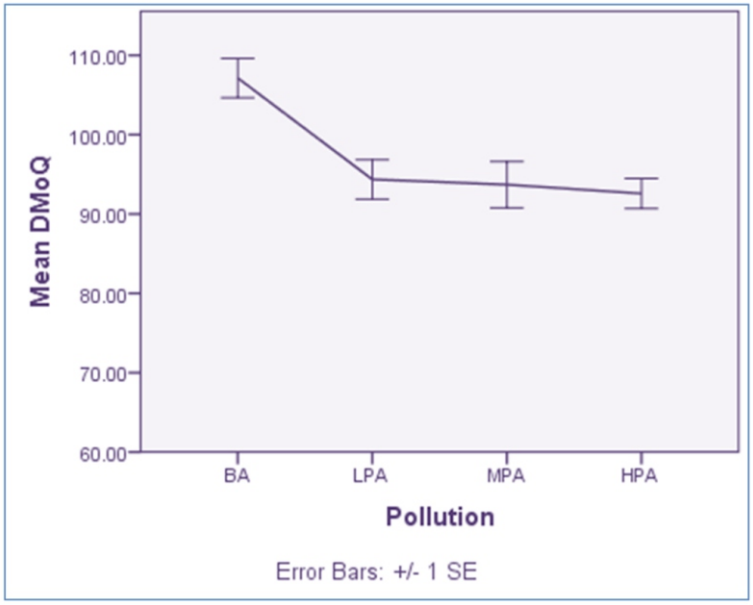


Fig. No. 3.2 Mean plot of Motor Development Quotients (DMoQ) of the infants of different pollution exposed and unexposed areas.

Table no. 3.5. ANNOVA of motor development quotient (DMoQ) of infants of different pollution exposed and unexposed areas.

Source	Degrees of Freedom	Sum Square	Mean Square	F-value (3,96)
Between Groups	3	3362.465	1120.822	7.423**
Within Groups	96	14495.906	150.999	
Total	99	17858.371		

**: $p< 0.01$

The difference between mean values of DMoQ of exposed and control group was found to be significant (F-ratio 7.423, p<0.0001). This shows that pollution exposure adversely affects the motor development of children. Thus, the null hypothesis that 'there will be no significant difference between the mean values of DMoQ of children of exposed area and background area' was rejected.

As per the norms of the DASII scale, DMoQ value of less than the standard value of 100 was considered as lower motor performance. Prevalence of lower motor performance among infants in three different pollution exposed areas and background areas are shown in table no. 3.6 and figure 3.3.

Table no. 3.6. Prevalence of Lower Motor Performance among infants of different pollution exposed (LPA, MPA & HPA) and unexposed areas (BA).

Area	N	Percent	O R (χ2)	LCL-UCL (95% C.I.)
BA (n=25)	6	24	1	0
LPA (n=25)	16	64	5.62(8.11**)	1.71-18.48
MPA (n=25)	14	56	4.03(5.33*)	1.23-13.15
HPA (n=25)	20	80	12.66(15.7**)	3.6-44.46

**: p< 0.05 & **: p< 0.01*

Prevalence of lower motor performance in subjects exposed to low pollution (LPA) (64%) was found to be higher in comparison to subjects exposed to moderate pollution (MPA) (56%). However, the prevalence of lower motor performance in all the three pollution exposed areas i.e., in the subjects exposed to low (LPA), moderate (MPA) and high (HPA) pollution was significantly higher in comparison to subjects from unexposed area BA (24%) (BA vs LPA, OR=5.62, p < 0.01, BA vs MPA, OR=4.03, p < 0.05 and BA vs HPA, OR=12.66, p < 0.01). The risk of lower motor performance was found to be associated with higher pollution level as shown in the figure 3.3

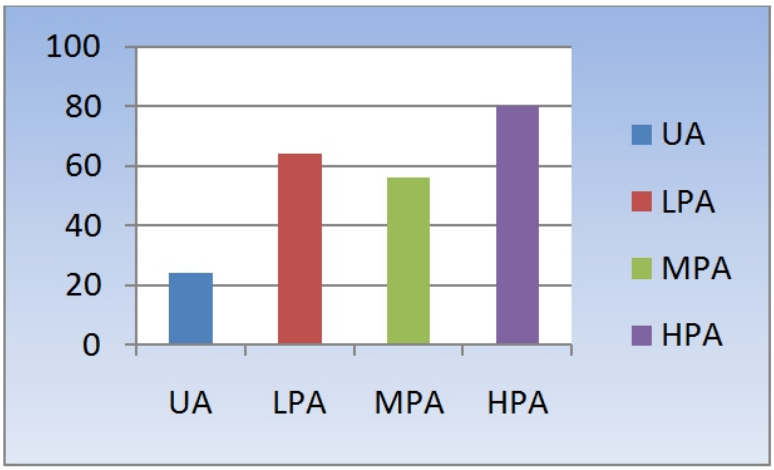


Figure.3.3. Prevalence (percentage) of lower motor performance

The motor development scale had five clusters of different number of motor items; neck control, body control, locomotion-1 (co-ordinated movements), locomotion-2 (skills) and manipulation. According to the percentile scores for various motor cluster given in the manual, raw score below the 50th percentile in the particular age range was considered as lower performance

on that mental variable. Similarly the total number of lower performances for all the five motor clusters/ variables was calculated and compared using chi-square test. Table no.3.7 shows the prevalence of lower performance on different motor variables among infants of different pollution level areas.

Table no. 3.7. Prevalence of lower performance on different motor development variables among infants of different pollution exposed areas (LPA, MPA, HPA) and unexposed area (UA or BA)

S.No.	Variable	N	%	O R (χ2)	LCL-UCL (95% C.I.)
	Area				
1	Neck Control				
	BA	0	0	0	**0**
	LPA	0	0	0	**0**
	MPA	0	0	0	**0**
	HPA	1	4	0	**0**
2	Body Control				
	BA	2	8	1	0
	LPA	10	40	7.66 (7.01**)	1.69-34.60
	MPA	9	36	6.46 (5.71*)	1.39-29.91
	HPA	12	48	10.61 (9.92**)	2.44-46.16
3	Locomotion-1				
	BA	2	8	1	0
	LPA	8	32	6.13 (4.99*)	1.24-30.10
	MPA	12	48	8.62 (8.25**)	1.98-37.50
	HPA	15	60	17.25 (15.06**)	4.09-72.67
4	Locomotion-2				
	BA	1	4	1	0
	LPA	1	4	1	0
	MPA	2	8	2.08 (0.35 NS)	0.18-23.50
	HPA	2	8	2.08 (0.35 NS)	0.18-23.50
5	Manipulation				
	BA	7	28	1	0
	LPA	12	48	2.37 (2.12NS)	0.74-7.59
	MPA	12	48	2.37 (2.12NS)	0.74-7.59
	HPA	13	52	2.78 (3NS)	0.87-8.88

**: p< 0.05, **: p< 0.01 & NS : Non Significant*

The major findings of comparison of prevalence of lower performance on different motor development variables among infants of different pollution exposed areas (LPA, MPA, HPA) and unexposed area (BA) using chi-square were :

- In case of 'neck control', none of the infants except one in HPA had shown lower performance in various areas.

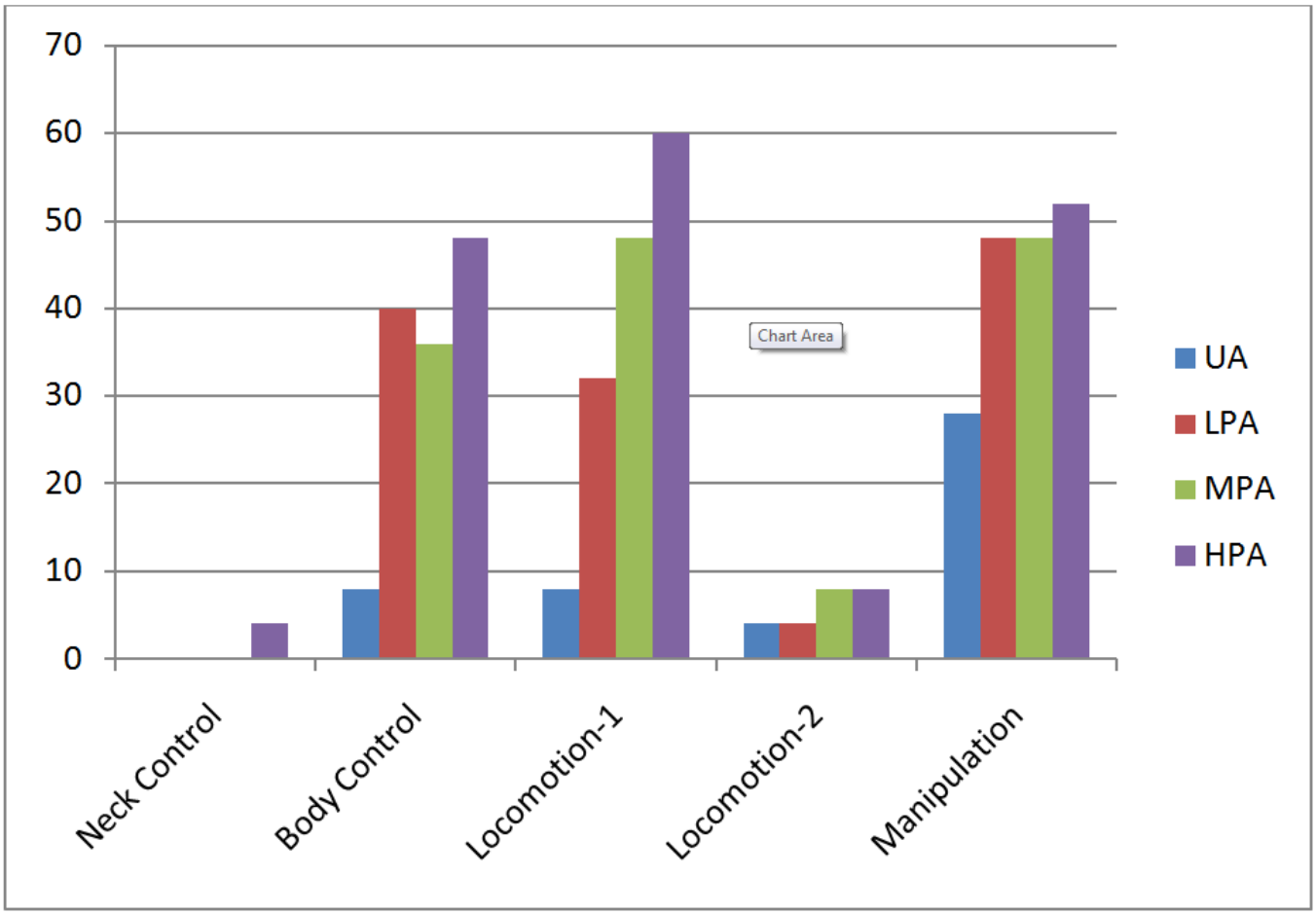


Figure no. 3.4. Prevalence (Percentage) of lower performance on different motor development variables among infants of different pollution exposed areas (LPA, MPA, HPA) and background areas (BA)

- In case of 'body control', the prevalence of lower performance was much greater in all the three exposed areas, low, moderate and high (40%, 36%, 48% respectively) polluted areas as compared to the background area (8%). However, the prevalence of lower performance in body control was slightly less in case of moderate pollution exposed infants (36%) as compared to the low pollution exposed infants (40%). The difference in lower performance as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=7.66, $p<0.01$; BA vs MPA, OR=6.46, $p<0.05$; BA vs HPA, OR=10.61, $p<0.01$) as shown in the table no. 3.7

- In case of 'locomotion-1' i.e., co-ordinated movements involved in walking and climbing steps, a greater percentage of infants showed lower performance in all the three exposed areas, low, moderate and high (32%, 48%, 60% respectively) polluted areas as compared to the background area (8%). The difference in lower performance as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=6.13, $p<0.05$; BA vs MPA, OR=8.62, $p<0.01$; BA vs HPA, OR=17.25, $p<0.01$) as shown in the table no. 3.7.

- In case of 'locomotion-2' i.e., locomotion skills, very few infants in all the four areas; background, low polluted, moderate polluted and high polluted areas (1,1,2,2 respectively) showed lower performance. Therefore, there were no significant differences in all the three exposed areas as compared to the background area.

- In case of 'manipulation', the prevalence of lower performance was higher in all three exposed areas; low, moderate and high polluted (48%, 48% & 52% respectively) as compared to the background area (28%). However, the difference of lower performance of the infants exposed to low, moderate and high pollution with respect to background area was not significant as revealed by the chi-square values (2.12 and 3) in the table.3.7.

-

F-test and chi-square test studied the effect of independent variable AAP on different motor development variables of infants. To study the effect of other socio-demographic factors like SES, gender and family size on different motor development variables of infants, Pearson correlation co-efficient were computed between them. The correlation coefficients are depicted in table no. 3.8.

Table no. 3.8 Correlations of motor development variables (DVs) of infants (0-2yrs) with pollution and family variables (Ivs)

	Pollution	Age	SES	Gender	Family Size
DMoQ	**-.368****	-.164	.143	**.210***	.044
Neck Control	-.128	.082	.005	-.112	-.019
Body Control	**-.207***	.064	-.010	-.067	.098
Locomotion1	-.087	-.123	.027	-.120	-.071
Locomotion2	-.032	**.557****	-.010	.100	.095
Manipulation	**-.261****	**.289****	.042	-.148	.057

**: p< 0.05; **: p< 0.01*

Pollution was found to be negatively correlated with all the aspects of motor and mental development of infants. As also revealed by the ANNOVA, the pollution was thus found to adversely affect the motor development of infants. Correlations were significant in case of DMoQ, body control and manipulation.

Age of infants was found to be positively correlated with all the aspects of motor development of infants. Correlations were significant in case of locomotion-2 and manipulation.

Gender was found to be significantly correlated ($r=0.21$, $p<0.05$) only in case of overall motor development (DMoQ) of infants. The boys of 0-2years were found to be more competent in overall motor development as compared to the girls of 0-2years.

No significant correlation was found between any of motor development variables and family variables; SES and family size.

Major Findings of Motor Development of Infants and Ambient Air Pollution:

1. The mean values of motor development quotient of 0-2 year children of the four study areas were found to decrease with increasing pollution levels. The mean value of motor development quotient was highest in case of infants of background area and lowest in HPA.
2. The difference between mean values of motor development quotient of infants of exposed areas and background area was found to be highly significant ($p<0.0001$).
3. The prevalence of lower performance in overall motor development

was significantly higher in all the three pollution exposed areas i.e., in the subjects exposed to low (LPA) ($p<.01$), moderate (MPA) ($p<.05$) and high (HPA) ($p<.01$) pollution areas in comparison to subjects from background area BA. The risk of lower motor performance was found to be associated with higher pollution level.

4. As per the sub-categories of motor development, the prevalence of lower performance was significantly higher in case of 'body control' and 'locomotion-1 (co-ordinated movements)' among infants of all three exposed areas; low, moderate and high polluted areas as compared to the background area.

5. The prevalence of lower performance was very less in case of 'neck control' and 'locomotion-2 (skills)' among infants of exposed and background area.

6. The prevalence of lower performance was not significantly higher in case of 'manipulation' among infants of all three exposed areas; low, moderate and high polluted areas as compared to the background area.

7. Pearson Correlation coefficient between independent variable; age and dependent variables; locomotion-2 and manipulation skills were found to be positive and significant.

8. Gender was found to be significantly correlated with the motor development quotient i.e., the overall motor development score of infants boys was found to be more as compared to the girls..

Discussion of Results:

Infancy is an important stage of human life which reflects the immediate effects of prenatal exposures to environmental pollutants. In the present study, the exposure to AAP on infants and children included the prenatal as well as the postnatal exposure as the children of the mothers who have been residing since past five years or more in the study areas were only included. Impact of prenatal exposure to AAP on behavior and development of young children has been an area of interest for the researchers previously also (Perera et al, 2006, 2009; Edwards et al. 2010; Guxens et al. 2014; Harris MH et al, 2015; Takashi Yorifuji et al. 2016).

Prenatal exposures to ambient air pollution might have affected the developmental processes of nervous system like maturation of the cortex (i.e., wiring; synaptic changes and axonal myelination) (Bellinger, 2013) and

further led to neuro-developmental problems like psychomotor problem in an infant. The psychomotor development of a child is a coordinated effort of muscles and nerves and is controlled by the motor cortex in the frontal cortex of brain (Pathak, 2001). Prenatal exposure to ambient air pollution has been linked to retarded and delayed growth of the fetus (Rich DQ et al, 2009; Choi H et al, 2008; Xu X, Sharma RK, et al, 2010; Wang X et al, 1997) which could further lead to poor coordination of muscles and nerves for body control and movements.

In our study, the motor development of infants was found to be adversely affected by the pre and post-natal ambient air pollution (PM10) exposure. The difference between the mean values of motor development quotient of infants of exposed areas and that of the background area was found to be significant ($p<0.0001$) through analysis of variance (ANOVA). Similar findings of decreased motor development quotients due to increase in the air pollutant polycyclic aromatic hydrocarbons (PAH) was found in the study by Tang et al, 2008. Tang, D. et al (2008) studied the associations between prenatal exposure to ambient PAH, lead and mercury from combustion of fossil fuels and cognitive functions measured by the Gessell Developmental Schedules at age two years among children in Tongliang and Chongqing, China. Increased PAH-DNA adducts in blood cords was found to be associated with decreased motor area development quotients.

Motor development of a child follows a predictive pattern. As per the cephalocaudal law, after the birth of a child, the motor control initiates from control over neck and later to other body parts. Thus, in our study the neck control which is to be achieved by an infant on average age of 2.8 months was attained by almost all of the infants. It can thus be assumed that the adverse effects of air pollution were not visible till the early age of 2.8 months. The other reason behind proper neck control among the infants of all the areas could be that neck control is the most basic and simple body movement involving predominantly the muscles of neck only. While, in case of coordinated movements involving limbs like walking, climbing the stairs (Locomotion-1) and whole body control, a significant difference was observed between the infants of exposed areas and background area. Whole body control investigated movements involving coordination between head, abdomen and limbs like sitting, standing, raising self to sitting, sitting down from standing position, turning or rolling from supine position to standing erect. These whole body coordination movements involving muscles of whole body of infants were found to be adversely affected by the ambient air pollution of the city. Guxens, M. etal (2014) also examined prenatal

exposure to outdoor air pollution and its effect on psychomotor development in 9482 children within six prospective cohort studies. The concentrations of air pollution were calculated using various procedures like air monitoring campaigns. A negative association was observed between prenatal air pollution, especially NO2 and psychomotor development in children aged 1-2 years.

As per the general sequence of motor development, the basic locomotion skills (Locomotion-1) like sitting, standing and walking develop earlier in infants and the finer motor skills (Locomotion-2) like holding a cup, scribbling with a pencil, jumping develop later on at the average age of 13.9 months (Pathak, 1997). In the present study the mean age of infants was observed to be 12.7 months (Table no.3.3). Only a few infants of the study were above 13 months. Hence, no significant difference could be observed among the infants of various study areas in case of 'locomotion-2'.

Lastly the lower performance on manipulative skills like finer grasping of objects and walking on the board, stairs etc. was higher in case of infants in background area as compared to other variables of motor development (neck control, body control, locomotion etc.) in infants of background area. The prevalence of lower performance on manipulative skills in three exposed areas was observed to be higher than the background area but, could not attain statistical significance. The possible reason could be lack of practice and training for the manipulative skills like clapping (mid line skill), throwing a ball, holding cubes and securing pellets given by the mothers to their infants due to unawareness in all the four study areas. Both maturation as well as learning are said to play an important role in acquiring these higher order manipulative motor skills. Similar evidences of no significant psychomotor development index at 12 and 24 months of age were reported by Kim E, et al (2014) in his prospective birth cohort study on the effect of prenatal exposure to the air pollutants, PM10 and NO2 on infants (0-24 months). The neurodevelopment was assessed using Korean Bayley Scale of Infant Development-II and air pollutants exposure was measured using inverse distance weighting model.

3.2.1.2.b. Mental Development of Infants and Ambient Air Pollution:

The DASII scale being used in the study has 163 items to assess the mental development of 0-2 year children. All the items are arranged in a progressive series. The raw scores obtained on the mental scale were converted into mental development quotient as per the norms given in the scale manual.

The mean values of mental development quotient (DMeQ) of infants are depicted in the table no.3.9.

Table no.3.9. .Mean values of Mental development quotients (DMeQ) of the infants (0-2years) of different pollution exposed (LPA, MPA & HPA) and unexposed areas (UA).

BA		LPA		MPA		HPA		Total	
Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
110.01	3.1	94.4	2.3	94.7	2.0	93.8	2.9	98.22	1.46

The mean values of DMeQ of infants of the four study areas were found to decrease with increasing pollution levels, except in case of MPA, the mean value of DMeQ (94.7) was slightly more than that in LPA (DMeQ=94.4) as also shown in figure no.3.5. The mean value of DMoQ was highest in case of background area (1107.01) and lowest in HPA (93.8) .

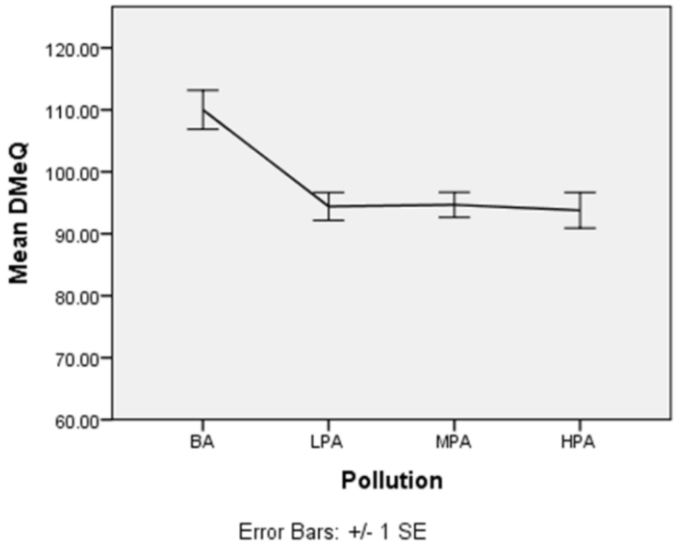


Figure no.3.5. Means Plot of Mental development quotients (DMeQ) of the infants (0-2years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

On comparing mean values of DMeQ of infants of various areas using the analysis of variance (table no 3.10), the difference between the DMeQ values of different exposed and background areas was found to be significant (F-ratio: 9.024, ($p<0.0001$). Thus, the null hypothesis that 'there will be no significant difference between the mean values of DMeQ of children of exposed area and background area' was rejected.

Table no. 3.10. ANOVA of mental development quotient (DMeQ) of infants of different pollution exposed and unexposed/background areas

Source	Sum of Squares	df	Mean Square	F
Between Groups	4644.938	3	1548.313	9.024**
Within Groups	16471.658	96	171.580	
Total	21116.596	99		

**: $p < 0.01$

Further, DMeQ value of less than the standard value of 100 was considered as lower mental performance. Prevalence of lower mental performance among infants in three different pollution exposed areas and unexposed areas are shown in table no. 3.11 and figure 3.6. Prevalence of lower mental performance in subjects exposed to low, moderate and high pollution (56%, 60% and 72% respectively) was found to be higher in comparison to subjects in unexposed area (16%). The difference was found to be statistically significant also as shown in the table no.6 (BA vs LPA, OR=6.68, p < 0.01, BA vs MPA, OR=7.87, p < 0.01 and BA vs HPA, OR=13.5, p < 0.01). The risk of lower mental performance was thus found to be associated with higher pollution level (figure no.3.6).

Table no. 3.11. Prevalence of Lower Mental Performance among infants of different pollution exposed (LPA, MPA & HPA) and unexposed areas (UA)

Area	N	Percent	OR(cl)	LCL-UCL (95% C.I.)
BA n=25	4	16	1	0
LPA n=25	14	56	6.68(8.68**)	1.88-23.64
MPA n=25	15	60	7.87(10.27**)	2.22-27.82
HPA n=25	18	72	13.5(15.9**)	3.75-48.5

**: $p < 0.01$

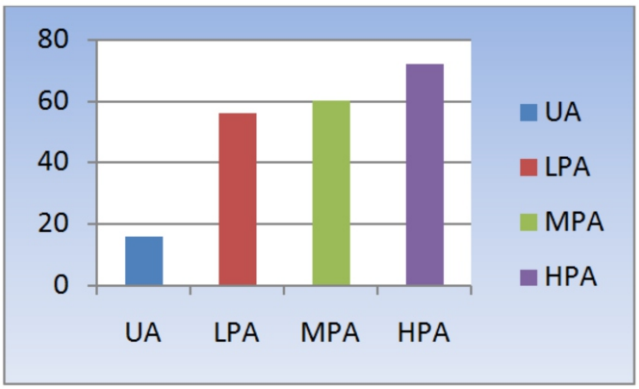


Figure.3.6. Prevalence (percent) of lower mental performance

The mental development scale of DASII had ten clusters of different number of mental items; 1) visual cognizance, 2) auditory cognizance, 3) reaching-manipulating-exploring, 4) memory, 5) social interaction- imitative behavior, 6) language-1: vocalization-speech-communication, 7) language-2: vocabulary-comprehension, 8) understanding of relationship, 9) differentiation by use, shapes and movements and 10) manual dexterity. Similar to the motor scale, as per the percentile scores for various mental cluster given in the manual, raw score below the 50th percentile in the particular age range was considered as lower performance on that mental variable. Similarly, the total number of lower performances for all the five motor clusters/ variables was calculated and compared using chi-square test. Table no.3.12 shows the prevalence of lower performance on different motor variables among infants of different pollution level areas.

Table no. 3.12. Prevalence of lower performance on different mental development variables amon infants of different pollution exposed areas (LPA, MPA, HPA) and unexposed area (UA)

S.No.	Variable	N	%	O R (χ2)	LCL-UCL
	Area				(95% C.I.)
1	Visual Cognizance				
	UA	1	4	1	0
	LPA	1	4	1	0
	MPA	2	8	2.08(0.35 NS)	0.18-23.05
	HPA	2	8	2.08(0.35 NS)	0.18-23.05
2	Auditory Cognizance				
	UA	0	0	0	0
	LPA	0	0	0	0
	MPA	2	8	0(2.08 NS)	0
	HPA	0	0	0	0
3	Reaching, M & Exploring				
	UA	5	20	1	0

	LPA	13	52	4.33 (5.55*)	1.28-14.66
	MPA	12	48	3.69 (4.36*)	1.08-12.57
	HPA	19	76	12.66(15.7**)	3.6-44.46
4	Memory				
	UA	2	8	1	0
	LPA	9	36	6.46 (5.71*)	1.39-29.91
	MPA	9	36	6.46 (5.71*)	1.39-29.91
	HPA	9	36	6.46 (5.71*)	1.39-29.91
5	Social Interaction & Imitative B				
	UA	3	12	1	0
	LPA	4	16	1.39 (0.16NS)	0.27-6.96
	MPA	4	16	1.39 (0.16NS)	0.27-6.96
	HPA	7	28	2.85 (2 NS)	0.66-12.18
6	Language 1				
	UA	2	8	1	0
	LPA	6	24	3.63(2.38NS)	0.7-18.68
	MPA	8	32	5.44(4.5NS)	1.13-25.75
	HPA	12	48	10.61(9.92**)	2.44-46.16
7	Language 2				
	UA	5	20	1	0
	LPA	8	32	1.88 (0.93NS)	0.52-6.78
	MPA	6	24	1.26 (0.11NS)	0.33-4.82
	HPA	7	28	1.55 (0.43NS)	0.42-5.75
8	Understanding Relationship				
	UA	3	12	1	0
	LPA	4	16	1.39 (0.16NS)	0.27-6.96
	MPA	8	32	3.45 (2.91NS)	0.83-14.3
	HPA	6	24	2.31 (1.21NS)	0.52-10.27
9	Differentiation by use,shape...				
	UA	2	8	1	0
	LPA	5	20	2.87 (1.49NS)	0.52-15.62
	MPA	6	24	3.63 (2.38NS)	0.7-18.68
	HPA	7	28	4.47 (3.38NS)	0.9-22.04
10	Manual Dexterity				
	UA	2	8	1	0
	LPA	0	0	0(2.08NS)	0
	MPA	2	8	1	0
	HPA	0	0	0(2.08NS)	0

**: p< 0.05; **: p< 0.01; NS: Non-significant*

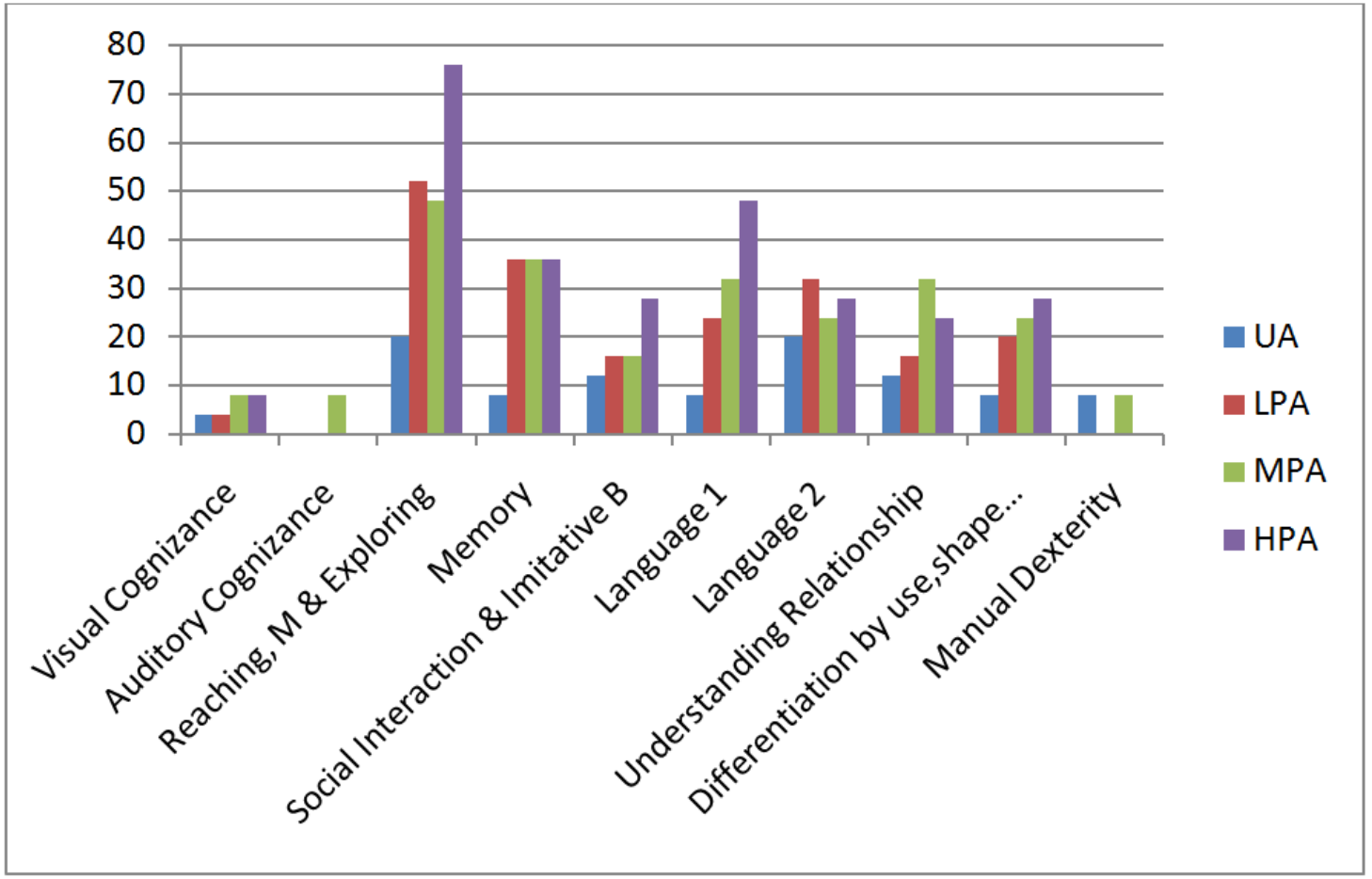


Figure no. 3.7. Prevalence (Percentage) of lower performance on different mental development variables among infants of different pollution exposed areas (LPA, MPA, HPA) and unexposed area (UA)

The major findings of comparison of prevalence of lower performance on different mental development variables among infants of different pollution exposed areas (LPA, MPA, HPA) and unexposed area (BA) using chi-square were :

- In case of 'visual cognizance', very few infants in all the four areas; background, low polluted, moderate polluted and high polluted areas (1,1,2,2 respectively) showed lower performance. Therefore, higher prevalence of lower performances in all the three exposed areas as compared to the background area were non-significant.

- In case of 'auditory cognizance', none of the infants except two in MPA had shown lower performance in various areas.

- In case of 'reaching-manipulating-exploring', the prevalence of lower performance was much greater in all the three exposed areas, low, moderate and high (52%, 48%, 76% respectively) polluted areas as compared to the background area (20%). However, the prevalence of lower performance in 'reaching-manipulating-exploring' was slightly less in case of infants exposed to moderate pollution (48%) as compared to the infants exposed to low pollution (52%). The difference in lower performance as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=4.33, $p<0.05$; BA vs MPA, OR=3.69, $p<0.05$; BA vs HPA, OR=12.66, $p<0.01$) as shown in the table no.3.12

- In case of 'memory', all the three exposed areas equal percentage of infants (36%) showed lower performance. However, in comparison to the background area (8%), the prevalence of lower performance on memory cluster in all the three exposed areas was statistically significant (chi-square:5.71).

- In case of 'social interaction- imitative behavior', the prevalence of lower performance was equal (16%) in infants exposed to lower and moderate pollution. This prevalence (16%) of lower performance in infants exposed to low and moderate pollution was found to be higher than the prevalence of lower performance in infants of background area (12%) but, the difference in the prevalence could not attain statistical significance (x^2 =0.16, $p>0.05$). Similarly, the prevalence of lower performance in infants exposed to high pollution (28%) was found to be higher than the prevalence of lower performance in infants of background area (12%) but, the difference in the prevalence could not attain statistical significance (x^2 =2, $p>0.05$).

- In case of 'language-1: vocalization-speech-communication', the prevalence of lower performance was higher in infants of all the three exposed areas; low, moderate and high polluted areas (24%, 32%, 48% respectively) in comparison to the infants in background area (4%). In all the three areas, the difference of lower performances in comparison with the background area was significant also as revealed by the chi-square values (4.15, 6.63 and 12.57 respectively).

- In case of 'language-2: vocabulary-comprehension', the prevalence of lower performance was higher in infants of all the three exposed areas; low, moderate and high polluted areas (32%, 24%, 28% respectively) in comparison to the infants in background area (20%). However, as shown in the table, in all the three areas, the difference of lower performances in comparison with the background area could not attain statistical significance ($p>0.05$).

- In case of 'understanding of relationship', the prevalence of lower performance was higher in infants of all the three exposed areas; low, moderate and high polluted areas (16%, 32%, 24% respectively) in comparison to the infants in background area (12%). However, as shown in the figure in all the three areas, the difference of lower performances in comparison with the background area could not attain statistical significance ($p>0.05$).

- In case of 'differentiation by use, shapes and movements', the prevalence of lower performance was higher in infants of all the three exposed areas; low, moderate and high polluted areas (20%, 24%, 28% respectively) in comparison to the infants in background area (8%). However, as shown in the table 3.12 in all the three areas, the difference of lower performances in comparison with the background area could not attain statistical significance ($p>0.05$).

- In case of 'manual dexterity', none of the infants in low and high polluted areas exhibited lower performance. Equal percentage (8%) of infants of moderate polluted and background area showed lower performance on manual dexterity test items.

To study the effect of other socio-demographic factors like SES, gender and family size on different mental development variables of infants, Pearson correlation co-efficient were computed between them. The correlation coefficients are depicted in table no.3.13.

Table no. 3.13 Correlations of mental development variables (DVs) of infants (0-2yrs) with pollution and family variables (Ivs)

	Pollution	Age	SES	Gender	Family Size
DMeQ	**-.373****	.034	.028	.164	.093
Visual Congnigance	**-.234***	**.261****	-.120	.172	.058
Auditory Congnigance	-.148	.018	.056	.031	.094
Manipulation (RME)	-.189	**.274****	-.131	.051	.097
Memory	-.118	**.268****	-.049	.079	.013
Social Interaction	**-.275****	.078	**.199***	.145	.098
Language1	**-.295****	.090	.151	.021	.039
Language2	.059	**.282****	.123	.058	.077
Understanding Relationship	**-.211***	**.210***	-.039	.125	**.197***
Differentiation by us	-.191	**.491****	.001	-.028	**.223***
Dexterity	.004	**.599****	-.063	.120	**.228***

**: p< 0.05; **: p< 0.01*

Pollution was found to be negatively correlated with all the aspects of mental development of infants. As also revealed by the ANNOVA, the pollution was thus found to adversely affect the mental development of infants. Correlations were significant in case of DMeQ, visual cognizance, social, language-1 and understanding relations.

Age of infants was found to be positively correlated with all the aspects of motor and mental development of infants. Correlations were significant in case of visual cognizance, manipulation, memory, language-2, understanding relationship', 'differentiation by use, shapes and movements' and 'manual dexterity'.

No significant correlation was found between gender, SES of the families of infants and various mental development variables.

Family size was found to be significantly correlated with only three aspects of mental development like 'understanding of relationship', 'differentiation by use, shapes and movements' and 'manual dexterity'.

Major Findings of Mental Development of Infants and Ambient Air Pollution:

1. The decreasing order of mean values of mental development quotient of 0-2 year children of the four study areas was BA>MPA>LPA>HPA. The mean value of DMeQ of infants in moderate polluted area was slightly more than that of infants in low polluted area. The mean value of mental development quotient was highest in case of infants of background area and lowest in HPA.

2. The difference between mean values of mental development quotient of infants of exposed areas and background area was found to be significant ($p<0.0001$).

3. The prevalence of lower performance in overall mental development was significantly higher in all the three pollution exposed areas i.e., in the infants exposed to low (LPA) ($p<.01$), moderate (MPA) ($p<.01$) and high (HPA) ($p<.01$) pollution areas in comparison to infants from background area BA. The risk of lower mental performance was found to be associated with higher pollution level.

4. In case of various sub-categories of mental development, the prevalence of lower performance was significantly higher in case of 'reaching-manipulating-exploring', 'memory' and 'language-1' (vocalization-speech-communication) among infants of all three exposed areas; low, moderate and high polluted areas as compared to the background area.

5. In case of sub-categories; visual cognizance, auditory cognizance and manual dexterity only a few infants of all the study areas had shown lower performance.

6. In case of all other sub-categories of mental development; social interaction- imitative behavior, language-2 (vocabulary-comp-rehension), understanding of relationship, and 'differentiation by use, shapes and movements', the prevalence of lower performance was not significantly higher among infants of all three exposed areas; low, moderate and high polluted areas as compared to the background area.

7. Pearson Correlation coefficient between age and independent variables, locomotion-2 and manipulation skills were found to be positive and significant.

8. Gender was found to be significantly correlated with the motor development quotient i.e., the overall motor development score of infants.

Discussion of Results:

Prenatal exposures to different pollutants have been consistently found to have profound effects on the mental development of infants similar to the motor development of infants. The child is in the sensory-motor stage of cognitive development during the infancy stage (0-2 years) and follows a predictive pattern of development as stated by Piaget. The child's learning

and attention processes are purely based on the sensory stimuli till 6 to 8 months. Gradually till the end of two years, the child develops the concept of object permanence and selective attention leading to perceptual products to store in memory [Piaget, 1970].

As revealed by the scores of the DASII scale, in the present study the mental development of infants was found to be adversely affected by ambient air pollution. The difference between the mean values of mental development quotient of infants of exposed areas and that of the background area was found to be significant ($p<0.0001$). The results were found to be in consistence with the findings of Guxens et al, 2012. The study focused on prenatal exposure to traffic related air pollution and the neuropsychological development of infants. The neuropsychological outcomes were measured by Bayley Scales of Infant Development. Residential NO_2 and benzene exposure during the whole pregnancy were observed to adversely and significantly affect the mental development of infants at around 14 months of age. The study was unique as it considered socio-economic factors, noise and cord blood lead as potential confounders.

In another study by Tang etal (2008), two identical small prospective cohorts enrolled non-smoking pregnant women and their newborn until two year old, one before and the other after the shutdown of the coal-burning plant. Prenatal PAH exposure was measured by PAH-DNA adducts in umbilical cord blood. Before the power plant shutdown, decreases in global IQ were associated with increased cord blood lead levels of PAH-DNA adduct.

Evidences prove that many of the air pollutants like particulate matter (PM) easily enter the brain directly through nasal olfactory mucosa due to its fine/ minute size (Genc,S. et al, 2012; Lucchini et al, 2012; Oberdoster et al, 2004; Peters et al, 2006). Oxidative stress and inflammation are the two major processes by which air pollutants like PM are believed to exert their toxicity on brain or the Central Nervous System (Mohan Kumar et al, 2008; Weldy et al, 2011). The prefrontal, parietal and occipital cortexes in the brain control the mental processes of visual and auditory cognizance, memory and language acquisition of children (Pathak, 2001). The neurotoxicity effects on any of these areas in the brain of infants could hamper these mental processes. Our study also differentiated the effect of particulate matter (PM10) on various aspects of mental/ cognitive development of infants. 'Reaching-manipulating-exploring', 'memory' and 'language-1' (vocalization-speech-communication) were the three areas of mental development which were investigated to be affected by the ambient air pollutant. In case of basic sensory processes like 'visual cognizance' and

'auditory cognizance', no significant difference was found in the lower performances of infants of the three exposed areas as compared to the infants in background area. However, in using those basic sensory processes at higher levels, in coordination with each other i.e., in reaching-manipulating-exploring and memorizing objects around them, and learning to vocalize-produce speech & communication (language development), significant differences were observed in the lower performances of infants of the three exposed areas as compared to the infants in background area. In a study by Lovasi et al (2014) prenatal exposure to PAH was found to be significantly associated with 3.9 point lower verbal scores among young children.

Thus, the mental development of the infants was found to be adversely affected by the air pollution in the city. The results were in consistence with the findings of earlier researches (Perera etal, 2006, Guxens et al, 2012; Kim. E. et al, 2004).

Perera etal (2006) studied the association between prenatal exposure to higher pollution level and the risk of lower mental performance. In a prospective cohort study, Perera etal evaluated the impact of prenatal exposure to urban pollutants polycyclic aromatic hydrocarbons, environmental tobacco smoke and pesticides. The women who participated in this cohort were Domnician or African-American non-smokers, free of diabetes, hypertension and HIV, did not use drugs and had resided in the area for at least one year. During the third trimester of pregnancy, personal PAH exposure was monitored for 2 consecutive days. BSID-Revised was used to assess the neuropsychological development of children. Infants of the mothers who had been exposed to the highest concentration of PAH, scored significantly lower mental development index (MDI) compared to the infants of the mothers that were lower exposed. The odds of having low MDI scores were 2.89 times higher in the high exposed children.

Lower performances in sub-categories of 'social interaction- imitative behavior', 'language-2 (vocabulary-comprehension)', 'understanding of relationship', and 'differentiation by use, shapes and movements' among infants of three exposed areas were not significantly higher in number as compared to the infants of background area.

Social interaction with adults and imitative behavior of infants were not found to be effected by the ambient air pollution (PM10). Prevalence of lower performance on items of social interaction and imitation of a person's behavior was found equally among the infants of the background area as

well as the three exposed areas. Similarly, on items of vocabulary comprehension (language-2) related to following instructions of the examiner like recognizing the pictures from the booklet, point objects around them, naming the parts of body etc., prevalence of lower performance was found equally among the infants of the background area as well as the three exposed areas. No significant difference was found in the background area and the three exposed areas. Similar findings of no significant association between prenatal air pollution (NO_2) and cognitive development in children of the age group 1-2 years in a study by Guxens et al (2014) was observed. Kim E. et al (2004) also reported no significant association between mental development index (MDI) at 12 and 24 months of age assessed using Korean- BSID and prenatal exposure to air pollution (PM_{10} & No_2).

In the present study, only a few infants of all the four areas were above 13 months. Hence, no significant difference could be observed in lower performances among the infants of background area and the three exposed areas in case of 'understanding of relationship', and 'differentiation by use, shapes and movements' and 'manual dexterity' as the age placement for these items was 14months and above.

3.2.2. Preschoolers (3-6years) of the Exposed and Background areas of Kanpur city:

A total of number of three hundred and twenty infants; eighty from each of the four areas; highly polluted (HPA), moderately polluted (MPA), least polluted (LPA) and background areas (BA) of the city were selected through purposive cum random sampling.

Table No. 3.14. Sample Size (3-6 Years/Preschoolers) (N=320)

Highly polluted area (HPA)	Moderately polluted area (MPA)	Least polluted area (LPA)	Background area (BA)
80	80	80	80

These preschoolers and their mothers were contacted at their respective houses or Anganwadi centre of the area. After establishing a good rapport with them, the personal information and specific information were collected.

3.2.2.1. General or related information of the preschoolers:

For collection of general information of the preschoolers, an interview schedule having items related to personal data, clinical examination, general diet pattern and subjective symptoms was used.. The data was

analysed using mean and percentage. SES was analysed using the modified Kuppuswamy's scale (Singh, Tulika etal, 2017) (AnnexureIV).

Similar to infants, the sample was drawn from the lower middle income group colonies to control the effect of intervening variables like parent's education level, occupation, income group. Preschoolers of the mothers who have been residing for six years or more in the study area were included in the sample.

Personal data sheet of each child was filled to collect all the related information. This personal data was analyzed in terms of percentage as shown below in the table 3.15

Table no.3.15. General Characteristics of the Preschoolers

S.No.	Personal Variable	BA	LPA	MPA	HPA	TOTAL
		N=80	N=80	N=80	N=80	N=320
	Mean (SE)					
1	Age (years)	4.2(0.11)	4.5(0.14)	**4.2(0.14)**	**4.4(0.11)**	**4.3(0.06)**
2	Weight (Kg)	13.4(0.18)	14(0.22)	12.1(0.2)	**14(0.29)**	**13.4(0.12)**
3	Height (cm)	98.9(0.91)	103(0.92)	94(1.09)	**103(1.27)**	**99.7(0.55)**
	Frequency (Percentage)					
1	**Gender**					
	Girls	40(50)	50(62.5)	40(50)	42(52.5)	172(53.75)
	Boys	40(50)	30(37.5)	40(50)	38(47.5)	148(46.25)
2	**Type of Family**					
a)	Nuclear	43(53.8)	56(70)	50(62.5)	45(56.25)	194(60.62)
b)	Joint	37(46.3)	24(30)	30(37.5)	35(43.75)	126(39.38)
3	**Total no. of Family Members**					
a)	3 to 4	24(30)	20(25)	31(38.75)	20(25)	95(29.69)
b)	5to 8	51(63.8)	51(63.75)	48(60)	46(57.5)	196(61.25)
c)	9 to 12	5(6.3)	9(11.25)	1(1.25)	14(17.5)	29(9.06)
4	**Socio-economic Class**					
a)	Upper Middle	10(12.5)	6(7.5)	1(1.25)	6(7.5)	23(7.19)
b)	Lower Middle	49(61.3)	51(63.75)	50(62.5)	53(66.25)	203(63.44)
c)	Upper Lower	16(20)	21(26.25)	24(30)	20(25)	81(25.31)
d)	Lower	5(6.3)	2(2.5)	5(6.25)	1(1.25)	13(4.06)

The mean age of preschoolers in the sample was 4.3 years. In all the four study areas it was found to be approximately four years. The mean weight of preschoolers was 13.4 kg and the mean height 99.7 cm. The values were within the reference range given by Indian Academy of Pediatricians (IAP, 2015) (Annexure no.I). The ratio of girls and boys was almost 50:50 in overall sample and most of the study areas, except in case of low pollution exposed areas, girls were found to be more (62.5%) in number as compared to the boys (37.5%) selected randomly for the sample. Majority (60.62%) of the families had nuclear type of family constitution having 5 to 8 family members as compared to the joint family structure (39.38%). In all the four study areas similar trend of popularity of nuclear family structure having mother-father and their children over joint family structure was found. Overall sample of preschoolers belonged to lower-middle SES (63.44%) as per Kuppuswamy's scale followed by upper-lower (25.31%), upper-middle (7.19%) then lower SES (4.06%). In all the four study areas, majority of the families (more than 60%) belonged to lower-middle SES. The trend of SES (lower-middle>upper-lower>upper-middle>lower) was similar in case of three study areas; BA, LPA and HPA. Only in case of moderate pollution area (MPA) the lower SES families were more in number (6.25%) as compared to upper-middle SES families (1.25%).

As per the observations during data collection, houses mainly had two or three rooms with proper ventilation and all the basic amenities like T.V., refrigerator, and cooking gas.

Mothers were also enquired about birth of the child, the details of their own feeding habits or any medication during pregnancy and the feeding habits of their child. In most of the cases it was a full term normal delivery under supervision of a registered medical practitioner in the hospital. No medication was done during pregnancy. None of the mothers reported to be consuming exceptional amount of fish or had any special craving habits like pica during pregnancy. All of them were engaged in four to five hours of household work daily during pregnancy. All preschoolers were breastfed till one year of age and were consuming a diet having cereals, pulses, vegetables and fruits mainly on an average daily. In addition, majority of the preschoolers were taking privilege of government's mid-day meal services at the anganwadi centre of the area on daily basis.

The preschoolers generally were found to be going to the Anganwadi for about four hours, if not then they were found to be playing outside during those hours. Apart from this, they were engaged in outdoor play activities for approximate two hours in the morning and two hours in the evening.

Rest of the time, they were inside their houses as reported by them. On an average a preschool child was reported to be spending eight hours outside their houses. Thus, the duration of exposure was almost similar for all the preschoolers of the study.

3.2.2.2. Specific Information/ Effect of ambient air pollution on different aspects of neuropsychological development of preschoolers (3-6 years) :

As per the age group of children (2-6years), the full IQ and six aspects of intelligence were measured as neuropsychological development variables.

'Stanford Binet Intelligence Scale by Kulshreshtha' was administered on the preschoolers and the full IQ and separate scores for the six sub-categories of intelligence; visual perception, motor co-ordination, language development, immediate memory, concept formation and reasoning were calculated.

After collection of data, the raw scores on the SB Test of various preschoolers were converted into full IQ as mentioned in the test manual. The mean values of intelligence quotients (IQ) of preschoolers on SB test in the four study areas are shown in the table no.3.16. The mean values of IQ of preschoolers of the four study areas were found to decrease with increasing pollution levels. The mean value of IQ was highest in case of background area (99.78) and lowest in HPA (93.13).

Table no. 3.16. Mean values of Intelligence quotients (IQ) of the preschoolers (3-6years) of different pollution exposed (LPA, MPA & HPA) and unexposed areas (BA).

BA		LPA		MPA		HPA		Total	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
99.78	1.54	97.71	1.56	95.95	1.64	93.13	1.89	96.64	0.84

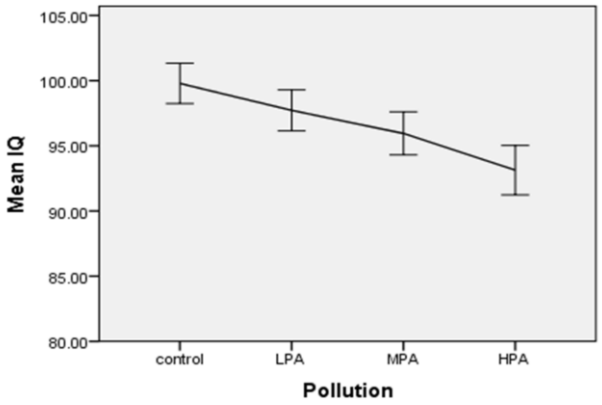


Figure no.3.8. Means Plot of Intelligence Quotients (IQ) of the preschoolers(2-6years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

To compare the mean values of IQ of preschoolers (figure no.) of various areas analysis of variance was applied. The difference between the mean IQ values of different exposed and background areas was found to be significant (F-ratio: 2.84, $p<0.05$). Thus, the null hypothesis that 'there will be no significant difference between the mean values of IQ of preschoolers of exposed area and background area' was rejected.

Table no. 3.17. ANOVA of intelligence quotient (IQ) of preschoolers of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	1906.506	635.502	2.84*
Within Groups	316	70623.447	223.492	
Total	319	72529.953		

**Significant at 0.05 level*

As per the norms of intelligence in the test manual, IQ value in the range of 90 to 110 is considered as an average intelligence. Thus, the IQ value of less than the 90 was considered as below average intelligence. Prevalence of below average intelligence among preschoolers in three different pollution exposed areas and background areas are shown in table no. 3.18 and fig.3.9

Table no. 3.18. Prevalence of below average intelligence among preschoolers of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

Pollution Level	N	Percentage	OR(χ2)	LCL-UCL (95% C.I.)
BA	24	30	1	0
LPA	26	32.5	1.12(0.11 NS)	0.57-2.19
MPA	29	36.25	1.32(0.70 NS)	0.68-2.56
HPA	38	47.5	2.11(5.16*)	1.1-4.02

Prevalence of below average intelligence in subjects exposed to low, moderate and high pollution (32.5%, 36.25% and 47.5% respectively) was found to be higher in comparison to subjects in background area (30%). But, the difference in the below average intelligence of preschoolers of low and moderate exposed areas and that of the preschoolers in the background area could not attain statistical significance ($p>0.05$) as shown by the chi-square values in the table no.. However, the difference between below average intelligence of preschoolers of highly exposed area and that of the preschoolers in background area was found to be statistically significant (BA vs HPA, OR=2.11, $p<0.05$)

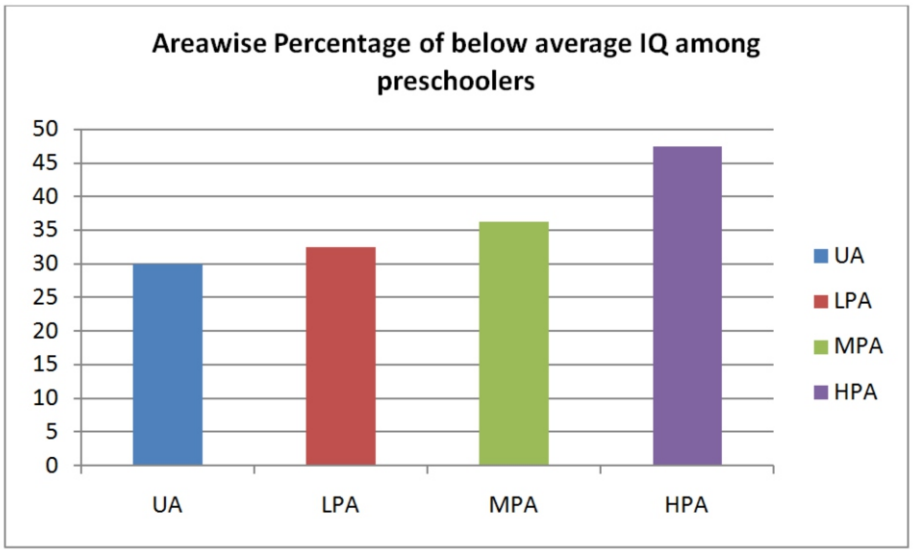


Figure no.3.9. Prevalence of below average intelligence among preschoolers of different pollution exposed areas (LPA, MPA, HPA) and background area (BA or UA)

The SB test had items related to six aspects of intelligence; visual perception, motor co-ordination, language development, immediate memory, concept formation, and reasoning. As per the scoring given in the methodology chapter, lower performances for each of the variable of intelligence in all the four study areas were counted and compared using chi-square test. Table no.3.19 shows the prevalence of lower performance on different intelligence variables among preschoolers of different pollution level areas.

Table no. 3.19. Prevalence of lower performance on different intelligence test variables among preschoolers of different pollution exposed areas (LPA, MPA, HPA) and background area (BA or UA)

S.No.	Variable	N	%	OR(χ2)	LCL-UCL (95% C.I.)
	Area				
1	Visual Perception				
	UA	19	23.75	1	0
	LPA	29	36.25	1.82(2.97 NS)	0.92-3.61
	MPA	31	38.75	2.03(4.18*)	1.03-4.0
	HPA	46	57.5	4.34(18.88**)	2.2-8.42
2	Motor Coordination				
	UA	3	3.75	1	0
	LPA	11	13.75	4.09(5*)	1.19-14.05
	MPA	12	15	4.52(5.95*)	1.34-15.23
	HPA	13	16.25	4.98(6.94**)	1.50-16.43
3	Language Dev & Compr.				

	UA	28	35	1	0
	LPA	29	36.25	1.05(0.02 NS)	0.55-2.01
	MPA	30	37.5	1.11(0.10 NS)	0.58-2.12
	HPA	51	63.75	3.26(13.22**)	1.72-6.18
4	Immediate Recall				
	UA	19	23.75	1	0
	LPA	26	32.5	1.54(1.51 NS)	0.77-3.09
	MPA	26	32.5	1.54(1.51 NS)	0.77-3.09
	HPA	30	37.5	1.92(3.55 NS)	0.75-2.82
5	Concept Formation				
	UA	25	31.25	1	0
	LPA	26	32.5	1.05(0.02 NS)	0.54-2.05
	MPA	28	35	1.18(0.25 NS)	0.61-2.28
	HPA	40	50	2.2(5.82*)	1.16-4.17
6	Reasoning				
	UA	15	18.75	1	0
	LPA	37	46.25	3.72(13.78**)	1.86-7.46
	MPA	36	45	3.54(12.69**)	1.76-7.11
	HPA	39	48.75	4.12(16.1**)	2.06-8.23

The major findings of comparison of prevalence of lower performance on different intelligence variables among infants of different pollution exposed areas (LPA, MPA, HPA) and background area (BA) using chi-square were:

- In case of 'visual perception', a greater percentage of preschoolers showed lower performance in all the three exposed areas, low, moderate and high (36.25%, 38.75%, 57.5% respectively) polluted areas as compared to the background area (19%). However, the difference in lower performance in preschoolers exposed to low pollution area as compared to the background area was not found to be statistically significant ($p>0.05$) as shown in the table. The difference in lower performance in preschoolers exposed to moderate and high pollution area as compared to the background area was found to be statistically significant (BA vs MPA, OR=2.03, $p<0.05$; BA vs HPA, OR=4.34, $p<0.01$).

- In case of 'motor co-ordination', a greater percentage of preschoolers showed lower performance in all the three exposed areas, low, moderate and high (13.75%, 15%, 16.25% respectively) polluted areas as compared to the background area (3.75%). The higher prevalence of lower performance as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=4.09, $p<0.05$; BA vs MPA, OR=4.52, $p<0.05$; BA vs HPA, OR=4.98, $p<0.01$)

- In case of 'language development and comprehension', a greater

percentage of preschoolers showed lower performance in all the three exposed areas, low, moderate and high (36.25%, 37.5%, 63.75% respectively) polluted areas as compared to the background area (35%). However, the difference in lower performance in preschoolers exposed to low and moderate pollution areas as compared to the background area could not attain statistical significant ($p>0.05$) as shown in the table 3.19. The difference in lower performance in preschoolers exposed to high pollution area as compared to the background area was found to be statistically significant (BA vs HPA, OR=3.26, $p<0.01$).

- In case of 'immediate recall memory', the prevalence of lower performance was equal (32.5%) in preschoolers exposed to low and moderate pollution. This prevalence (32.5%) of lower performance in preschoolers exposed to low and moderate pollution was found to be higher than the prevalence of lower performance in preschoolers of background area (23.75%) but, the difference in the prevalence could not attain statistical significance (χ^2 =1.51, $p>0.05$). Similarly, the prevalence of lower performance in preschoolers exposed to high pollution (37.5%) was found to be higher than the prevalence of lower performance in preschoolers of background area (23.75%) but, the difference in the prevalence could not attain statistical significance (χ^2=3.55, $p>0.05$).

- In case of 'concept formation', a greater percentage of preschoolers showed lower performance in all the three exposed areas; low, moderate and high polluted areas (32.5%, 35% & 50% respectively) as compared to the background area (31.25%). However, the difference in lower performance in preschoolers exposed to low and moderate pollution areas as compared to the background could not attain statistical significance ($p>0.05$) as shown in the table3.19. The difference in lower performance in preschoolers exposed to high pollution area as compared to the background area was found to be statistically significant (BA vs HPA, OR=2.2, $p<0.05$).

- In case of 'reasoning', a greater percentage of preschoolers showed lower performance in all the three exposed areas; low, moderate and high polluted areas (46.25%, 45% & 48.75% respectively) as compared to the background area (18.75%). However, in case of moderate pollution area, the percentage of lower performance in preschoolers on reasoning items (45%) was less than the percentage of lower performance in preschoolers on reasoning items in low polluted area (46.25%). The difference in lower reasoning performance in preschoolers exposed to low, moderate and

high pollution areas as compared to the background area was found to be statistically significant (BA vs LPA, OR=3.72, p<0.01, BA vs MPA, OR=3.54, p<0.01, BA vs HPA, OR=4.12, p<0.01).

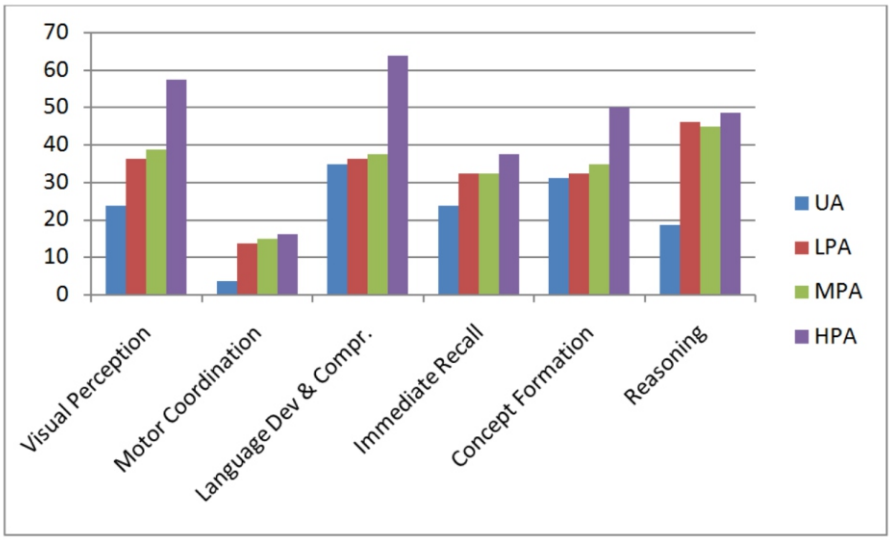


Figure no. 3.10. Prevalence (Percentage) of lower performance on different intelligence test variables among preschoolers of different pollution exposed areas (LPA, MPA, HPA) and background area (BA or UA)

After studying the effect of independent variable AAP on different neuropsychological variables of preschoolers, the effect of intervening socio-demographic factors like SES, gender and family size on different neuropsychological variables of preschoolers were studied. The Pearson correlation co-efficient between various neuropsychological variables and the socio-demographic variables were obtained. The correlation coefficients are depicted in table no. 3.20.

Table no. 3.20. Correlations of neuropsychological variables (DVs) of preschoolers (3-6 yrs) with pollution and family variables (Ivs)

	Pollution	Age	Gender	SES	FamilySize
Full IQ	**-.161****	-.059	-.004	**.122***	.003
VisualPercpn	**-.207****	-.095	-.024	**.124***	.064
MotorCordn	**-.231****	**.147****	.020	.017	-.021
LangDev	-.015	-.092	.009	.044	-.052
ImmRecall	**-.200****	-.055	-.009	.066	.025
ConceptFormn	-.032	-.034	.013	.051	.055
Reasoning	**-.223****	-.096	.066	**.147****	.009

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Pollution was found to be negatively correlated with almost all the aspects of intelligence of preschoolers. As also revealed by the ANOVA, the pollution was thus found to adversely affect the neuropsychological development of infants. Correlations were significant ($p<0.01$) in all the cases of full IQ, visual perception, motor co-ordination, immediate recall and reasoning except language development and concept formation as shown in the above table.

Intelligence was not found to be significantly correlated with age of preschoolers.

No significant correlation ($p>0.05$) was found between SES of the families and most of the neuropsychological variables of preschoolers. However, the correlation between full IQ, visual perception, and reasoning ($r=0.122$, 0.124 and 0.147 respectively) was found to be significant and positive.

Gender was not found to be significantly correlated with any of the neuropsychological variables of preschoolers. The boys and girls of 2-6 years were found to be equally competent in motor and mental development.

No significant correlation ($p>0.05$) was found between any of the aspects of neuropsychological development of preschoolers and family size. Family size showed no significant effect on any of the aspects of intelligence of preschoolers.

As none of the associations between the neuropsychological variables (dependent variables) and the personal & family variables (intervening variables) appeared to be strong ($r<0.3$), further regression analysis was not needed. The effect of all the intervening variables; age, gender, SES and family size on various neuropsychological variables was found to be negligible.

Major Findings of neuropsychological development of preschoolers and AAP :

1. The mean values of intelligence quotient (IQ) of 2-6 years old children of the four study areas were found to decrease with increasing pollution levels. The decreasing order of mean values of IQ of children of the four study areas was BA>LPA>MPA>HPA. The mean value of IQ of preschoolers was highest in case of background area and lowest in highly polluted area (HPA).
2. The difference between mean values of intelligence quotient of preschoolers of exposed areas and background area was found to be significant ($p<0.05$) through analysis of variance.

3. Prevalence of below average intelligence in preschoolers exposed to low, moderate and high pollution was found to be higher in comparison to subjects in background area. However, the difference between below average intelligence of preschoolers of highly exposed area (HPA) and that of the preschoolers in background area could only attain statistical significance ($p<0.05$) as revealed by the chi-square test.

4. The odds of having below average intelligence were 2.11 times higher in the preschoolers of highly exposed area.

5. On calculating the prevalence of lower performance on different intelligence test variables among preschoolers of different pollution level areas, it was observed that in case of 'visual perception', 'motor coordination' and 'reasoning', the prevalence of lower performances in preschoolers of the three exposed areas were greater than that of the preschoolers of the background area. These differences between the prevalence of lower performances in preschoolers of the three exposed areas and that of the preschoolers of the background area were found to be significant except in case of 'visual perception' scores of preschoolers of LPA. The difference between the prevalence of lower performance of the low pollution exposed area (LPA) and that of the preschoolers of the background area on items of 'visual perception' was found to be non-significant.

6. In case of 'language development and comprehension' and 'concept formation' the prevalence of lower performances of preschoolers were observed to be significantly greater only in case of high polluted areas (HPA) with respect to that in preschoolers of background area.

7. Immediate recall' was the only aspect of intelligence, in which there was no significant difference in the prevalence of lower performances among the preschoolers of any of the three pollution exposed areas in comparison to the preschoolers of background area.

8. The values of Pearson correlation coefficients ($r<0.2$) revealed that none of the intervening variables; age, gender, SES and family size were strongly or moderately associated with the intelligence variables, all the associations were very weak. The variance in all the intelligence variables was mainly due to the effect of AAP.

Discussion of Results:

The early exposure to environmental pollutants may interfere with critical developmental processes of the nervous system. Longitudinal studies suggest that younger children may be particularly susceptible to the environmental influences on intelligence. Although heritability becomes a strong predictor of IQ as children grow older, these studies estimated that heritability of IQ contributes about 30% in early childhood and increases to more than 50% in adulthood (Brant et al,2009; Deary et al 2007; Van Soelen et al, 2011).

Consistent with the findings of these studies, in the present investigation the intelligence quotient of preschoolers was found to be significantly and adversely affected by the ambient air pollution (PM_{10}) of the city. Especially in case of highly polluted area, the lower performance of preschoolers on IQ test (SB test) was reported to be significantly greater in number as compared to the preschoolers in background area.

The odds of lower performance among the preschoolers on various aspects of intelligence of low exposed area (PM_{10} about two times the standard value of 60 µgm/ m^3), moderate exposed area (PM_{10} about three times the standard value of 60 µgm/ m^3) and highly exposed areas (PM_{10} about four times the standard value of 60 µgm/ m^3)were found to be 2 to 4 times higher as compared to the background area (PM_{10} about 60 µgm/ m^3) .

Several other studies have reported similar findings of lower IQ of preschoolers due to ambient air pollutants. Lovasi et al (2014), examined the effects of prenatal exposure to PAH and neighbourhood social context on cognitive test scores. Pregnant African American and Domnician women between the age of 18 to 35 from a medical centre in New York were considered for prenatal exposure. Personal air monitors were used to measure the prenatal PAH exposure for two consecutive days. Weschlers Preschool and Primary Scale of Intelligence- Revised was used to measure the cognitive test scores. The prenatal PAH exposure was found to be significantly associated with lower total IQ scores and lower verbal scores among their five year old children. Similarly in our study also, the odds of having below average intelligence were 2.11 times higher in the preschoolers of highly exposed area. Thus, more exposed children were found to be more at risk for mental performance deficits. The odds of lower language development & comprehension and concept formation were observed to be higher (3.26 and 2.2 times respectively) in the preschoolers of highly

exposed area (PM_{10} four times the standard value of 60 μgm/ m^3) as compared to the background area (PM10 about 60 μgm/ m^3).

In another investigation Freire C et al (2010) studied the impact of traffic related air pollution (TRAP) on the cognitive development of preschoolers in Granada (Spain). Specifically residential NO_2 exposure was assessed using land use regression modeling. A non-significant reduction of general cognition, quantitative and working memory among the preschoolers exposed to NO2 compared to their counterparts was found. Similar to the study by Freire C et al, in the present study, the prevalence of lower performance on immediate recall memory sub-test among the preschoolers of the three exposed areas although greater than that of the preschoolers of background area but, could not attain significant difference.

In a related study Morales E et al (2009) reported a negative association between early life exposure to household gas appliances, indoor NO_2 levels and general cognitive functioning at age 4 years. A higher risk for development of ADHD Attention Deficit Hyperactivity Disorder due to the exposure was also found. The major symptoms of ADHD being inattention and impulsivity, the study supports the results of the present research work. In the present research, the performance on 'visual perception' sub-test items, the basic requirement for attention was found to be affected by the AAP.

Harris M H et al (2015) studied effect of traffic related air pollution on children. Roadway proximity; pre and postnatal exposure to PM2.5, Black Carbon was found to be associated with detrimental nonverbal IQ and visuo-motor abilities. The results were found to be consistent with the findings of present study.

The odds of lower reasoning were observed to be 3.5-4.12 times higher in the preschoolers of low, moderate and highly exposed area as compared to the background area, suggestive that preschoolers of AAP exposed were more at risk to lower reasoning performance as compared with the children of clean area. The result is supported by the studies of Edwards et al. (2010), Cowell et al (2015) and Chiu et al (2016). Edwards et al found an association between prenatal exposures to airborne PAH and poorer non-verbal reasoning at 5 years of age. Cowell et al investigated the effects of prenatal traffic related black carbon exposure on children's memory and learning. LUR models were used to study the BC exposure. The wide range assessment of memory and learning- 2nd ed. (WRAML2) was used to assess memory functions. Boys born to mothers with higher prenatal BC exposure

showed lower memory score. Chiu et al reported that increased prenatal exposure to $PM_{2.5}$ was associated with poorer functions across memory and attention domains.

3.2.3. School-going (7-12 years) of the Exposed and Background areas of Kanpur city:

A total of number of three hundred and twenty school-going children; eighty from each of the four areas; highly polluted (HPA), moderately polluted (MPA), least polluted (LPA) and background areas (BA) of the city were selected through purposive cum random sampling.

Table No. 3.21. Sample Size (7-12 Years/School going children) (N=320)

Highly polluted area (HPA)	Moderately polluted area (MPA)	Least polluted area (LPA)	Background area (BA)
80	80	80	80

These school-going children and their mothers were contacted at their respective houses or government primary school of the area. After establishing a good rapport with them, the personal and specific information were collected.

3.2.3.1. General or related information of the school-going children :

For collection of general information of the school-going children, an interview schedule having items related to personal data, clinical examination, general diet pattern and subjective symptoms was used.. The data was analysed using mean and percentage. SES was analysed using the modified Kuppuswamy's scale (Singh, Tulika etal, 2017) (Annexure IV).

Similar to infants and preschoolers, the sample of school-going children was drawn from the lower middle income group colonies to control the effect of intervening variables like parent's education level, occupation, income group. School-going children whose mothers have been residing for less than six years in the study area were not included in the sample.

Personal data sheet of each child was filled to collect all the related information. This personal data was analyzed in terms of percentage as shown below in the table 3.22.

Table no.3.22. General Characteristics of the School-going Children

S.No.	Personal Variable	UA	LPA	MPA	HPA	TOTAL
		N=80	N=80	N=80	N=80	N=320
	Mean (SE)					
1	Age (years)	9.52	9.25	10.5	8.9	9.54
2	Weight (Kg)	21.8	23.08	26.9	25.9	24.42
3	Height (cm)	127.7	127.8	130.9	126.8	128.3
	Frequency (Percentage)					
1	**Gender**					
	Girls	44(55)	36(45)	50(62.5)	32(40)	162(50.62)
	Boys	36(45)	44(55)	30(37.5)	48(60)	158(49.38)
2	**Type of Family**					
a)	Nuclear	52(65)	55(68.75)	67(83.75)	60(75)	234(73.12)
b)	Joint	28(35)	25(31.25)	13(16.25)	20(25)	86(26.88)
3	**Total no. of Family Members**					
a)	3 to 4	13(16.25)	20(25)	20(25)	24(30)	77(24.06)
b)	5to 8	52(65)	39(48.75)	47(58.75)	44(55)	182(56.87)
c)	9 to 12	15(18.75)	21(26.25)	13(16.25)	12(15)	61(19.06)
4	**Socio-economic Class**					
a)	Upper Middle	0	0	0	0	0
b)	Lower Middle	16(20)	36(45)	19(23.8)	17(21.25)	88(27.5)
c)	Upper Lower	64(80)	40(50)	60(75)	63(78.75)	227(70.93)
d)	Lower	0	4(5)	1(1.25)	0	5(1.56)

The mean age of school-going children selected for the sample was 9.5 years. In all the four study areas it was found to be approximately nine or ten years. The mean weight of preschoolers was 24.42 kg and the mean height 128.3 cm. The values were within the reference range given by Indian Academy of Pediatricians (IAP, 2015) (Annexure no.I). The ratio of girls and boys was almost 50:50 in overall sample. Majority (73.12%) of the families had nuclear type of family constitution as compared to the joint family structure (26.88%). In all the four study areas similar trend of popularity of nuclear family structure having mother-father and their children over joint family structure was found. The total number of family members in majority (56.87%) of the families was 5 to 8. Overall sample of school-going children belonged to upper-lower SES (70.93%) followed by lower-middle SES (27.5%), then lower SES (1.56%) families as per Kuppuswamy's scale. In all the study areas except LPA (50%), majority of the families (more than 75%) belonged to upper-lower SES. The trend of SES in families was similar (upper-lower>lower-middle>lower) in all the four study areas; BA, LPA, MPA

and HPA. In case of background area (BA) and highly polluted area (HPA) none of the school-going child belonged to the lower SES family.

As per the observations during data collection, houses mainly had two or three rooms with proper ventilation and all the basic amenities like T.V., refrigerator, and cooking gas.

Mothers were also enquired about birth of the child, the details of their own feeding habits or any medication during pregnancy and the feeding habits of their child (Table 3.22). In most of the cases it was a full term normal delivery under supervision of a registered medical practitioner in the hospital. No medication was done during pregnancy. None of the mothers reported to be consuming exceptional amount of fish or had any special craving habits like pica during pregnancy. All of them were engaged in four to five hours of household work daily during pregnancy. All the school-going children were breastfed till one year of age and were consuming a diet having cereals, pulses, vegetables and fruits mainly on an average daily. In addition, majority of the school-going children were found to be consuming the mid-day meal distributed in the government primary school of the area on daily basis.

On enquiry about the personal activity pattern of the school-going children, it was investigated that the children were usually going to schools for six hours, going outside to attend tutions for about two hours and for another two hours, they were playing outside. Rest of the time they were staying inside their houses. Thus, the duration of exposure was almost similar for all the school-going children.

3.2.3.2. Specific Information/ Effect of ambient air pollution on different aspects of neuropsychological development of school-going children (7-12 years) :

As per the age group of children (6-12years), various domain specific tests were applied on the school-going children of various exposed areas (LPA, MPA, HPA) and background area (BA) to study the effect of ambient air pollution on their neuropsychological development. Neuropsychological development variables measured were full IQ, attention/ short-term forward memory, executive function/ short-term backward memory, vocabulary knowledge, visuo-spatial ability, immediate and delayed recall memory, recognition memory, processing speed and accuracy and finger dexterity. All the tests were short tests, consuming very less time (five to fifteen minutes) and were used in a specific sequence in form of a test battery.

The results in this section are being discussed under following heads:

a. Intelligence of School-going Children and Ambient Air Pollution

b. Attention of School-going Children and Ambient Air Pollution

c. Executive Function of School-going Children and Ambient Air Pollution

d. Vocabulary of School-going Children and Ambient Air Pollution

e. Visuo-spatial ability of School-going Children and Ambient Air Pollution

f. Immediate Recall Memory of School-going Children and Ambient Air Pollution

g. Delayed Recall Memory of School-going Children and Ambient Air Pollution

h. Recognition Memory of School-going Children and Ambient Air Pollution

I. Perceptual Speed & Accuracy of School-going Children and Ambient Air Pollution

j. Right Hand Dexterity of School-going Children and Ambient Air Pollution

k. Left Hand Dexterity of School-going Children and Ambient Air Pollution

l. Both Hand Dexterity of School-going Children and Ambient Air Pollution

3.2.3.2.a. Intelligence (IQ) of School-going Children and Ambient Air Pollution

The general intelligence or full IQ of school-going children was measured using the Developmental Screening Test (DST) by J. Bharat Raj. The mean scores of full IQ on DST of the school-going children in the four study areas are shown in the table no.3.23. The mean scores of IQ of school-going children of the three exposed and background areas were found to decrease with increasing pollution levels. The decreasing order of mean scores of IQ in the four study areas was: BA>LPA>MPA>HPA. The mean score of IQ was highest in case of background area (102.43) and lowest in HPA (96.44) (figure no. 3.11).

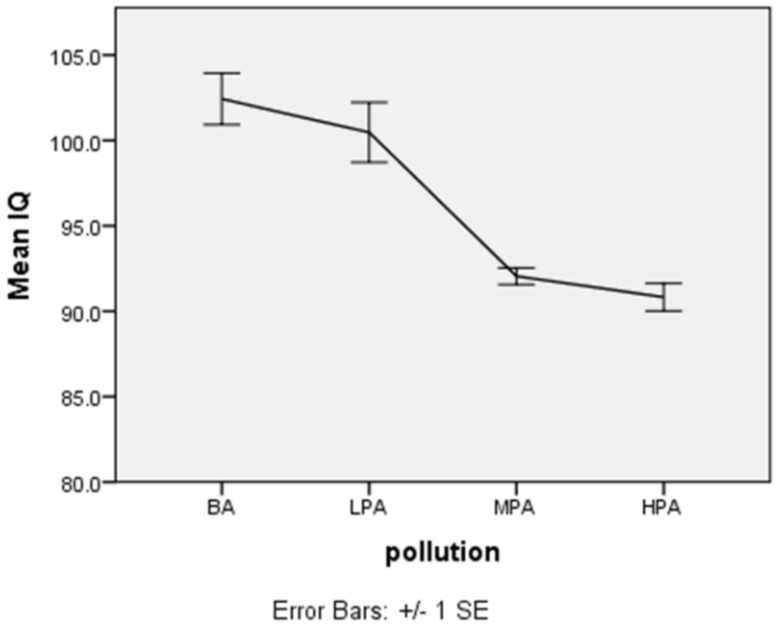


Figure no.311.. Means Plot of Intelligence Quotients (IQ) of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

Table no. 3.23. Mean scores of IQ of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
102.43	1.5	100.47	1.75	92.05	0.49	90.82	0.8	96.44	0.68

The mean scores of IQ of school-going children (figure no. 3.11) of various exposed areas and background area were compared using analysis of variance (Table no.3.24).

Table no.3.24. ANOVA of IQ scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	8236.78	2745.59	21.98**
Within Groups	316	39466.65	124.89	
Total	319	47703.43		

***: p <0.01*

The difference between the mean scores of IQ of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be significant (F=21.98, p<0.01). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of IQ of school-going children of exposed area and background area' was rejected.

The number of children below average intelligence was calculated as per the norms given in the manual of DST. The prevalence of below average intelligence in all the four areas was compared using chi-square test. The odds or the risk of getting below average intelligence in the three exposed groups as compared to the control group was also calculated.

Table no.3.25. Prevalence of below average intelligence among school-going children in three different pollution exposed areas and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	7	8.75	1	0
LPA (n=80)	17	21.25	2.8(4.9*)	1.12-7.03
MPA (n=80)	19	23.75	3.2(6.6*)	1.32-7.97
HPA (n=80)	36	45	8.5(26.7**)	3.78-19.22

**: p<0.05, **: p<0.01*

As reveals through the table no.3.25, a greater percentage of school-going children showed below average intelligence in all the three exposed areas, low, moderate and high (21.25%, 23.75%, 45% respectively) polluted areas as compared to the background area (8.75%). The difference in below average intelligence as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=2.8, p<0.05; BA vs MPA, OR=3.2, p<0.05; BA vs HPA, OR=8.5, p<0.01).

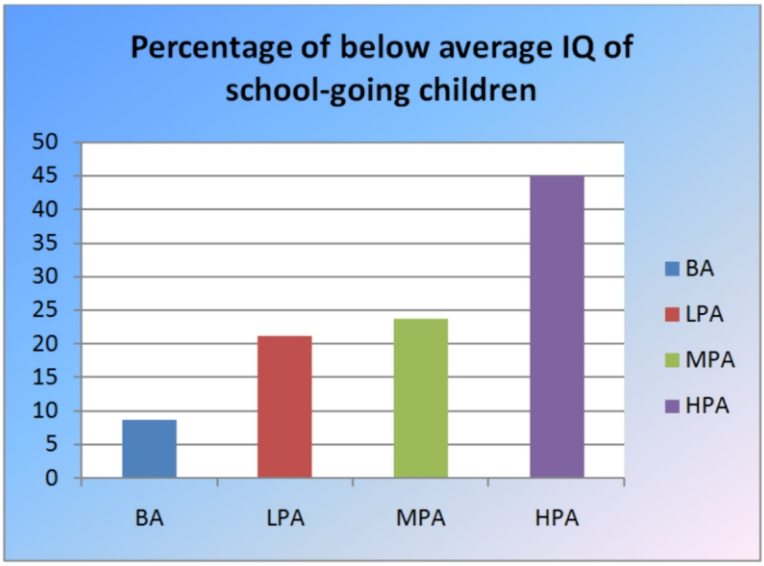


Figure no. 3.12. Prevalence (Percentage) of below average IQ among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

3.2.3.2.b. Attention of School-going Children and Ambient Air Pollution

Attention or concentration of school-going children was measured using digit span forward (DSF) a part of Malin'test (Indian adaptation of Weschler's Scale of Intelligence for Children). The mean scores of Attention on DSF test of the school-going children in the four study areas are shown in the table no.3.26. The mean scores of Attention of school-going children of the three exposed and background areas were found to decrease with increasing pollution levels. The decreasing order of mean scores of Attention in the four study areas was: BA>LPA>MPA>HPA. The mean score of Attention on DSF test was highest in case of background area (4.56) and lowest in HPA (2.69) as also shown in figure no. 3.13.

Table no. 3.26. Mean scores of Attention (DSF) of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
4.56	0.15	4.4	0.16	4.3	0.2	2.69	0.22	3.99	0.1

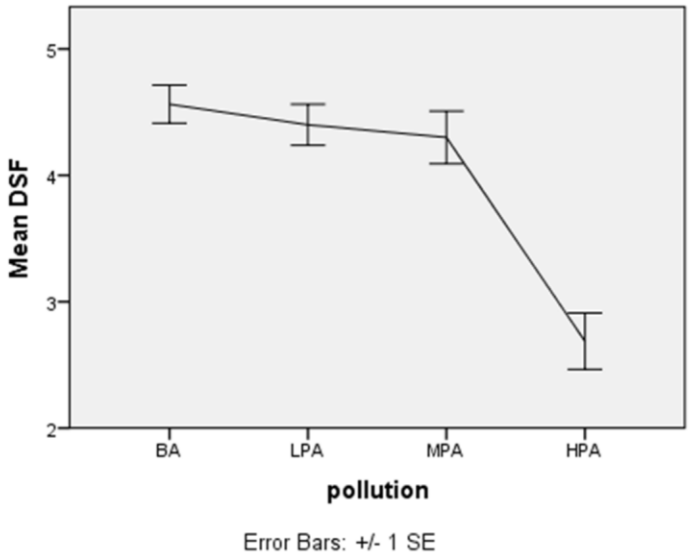


Figure no.313.. Means Plot of Attention (DSFscores) of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Attention/DSF of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be significant ($F=21.98$, $p<0.01$) as revealed by the analysis of variance (Table no.3.27). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Attention/DSF of school-going children of exposed area and background area' was rejected.

Table no. 3.27. ANOVA of Attention/DSF scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	183.08	61.03	21.45**
Within Groups	316	898.88	2.84	
Total	319	1081.95		

***: p<0.01*

The lower performances on Digit Span Forward (DSF) test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Attention test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.28. Prevalence of lower performances on DSF test/ Attention among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
UA (n=80)	8	10	1	0
LPA (n=80)	12	15	1.58(0.91 NS)	0.61-4.09
MPA (n=80)	23	28.75	3.63(9**)	1.53-8.43
HPA (n=80)	38	47.5	8.14(27.45**)	3.71-17.84

*NS: Non significant, **: p<0.01*

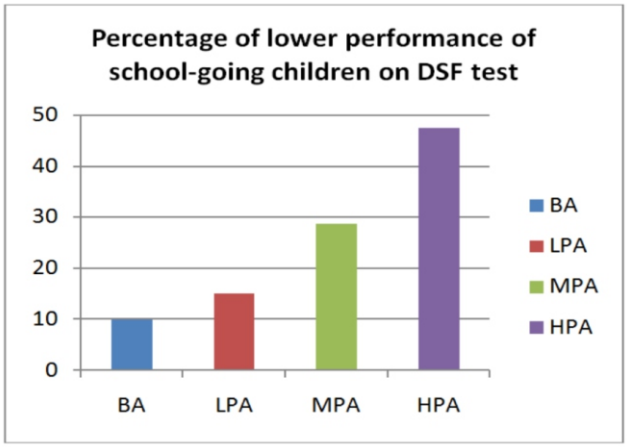


Figure no. 314.. Prevalence (Percentage) of lower performance on digit span forward (DSF) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

As shown in the table no. 3.28, a greater percentage of school-going children revealed lower performance on the DSF in all three exposed areas; low, moderate and highly polluted areas (15%, 28.75% & 47.5% respectively) as compared to the background area (10%). However, the higher prevalence of lower performance on the DSF in school-going children exposed to low pollution areas as compared to the background could not attain statistical significance ($p>0.05$) as shown in the table. The higher prevalence of lower performance on the DSF in school-going children exposed to moderate and high pollution area as compared to the background area was found to be statistically significant (UA vs MPA, OR=3.63, $p<0.01$; UA vs HPA, OR=8.14, $p<0.01$).

3.2.3.2.c. Executive Function of School-going Children and Ambient Air Pollution

The Executive Function of school-going children was measured using digit span backward (DSB) sub-test of Malin'test. The mean scores of Executive Function on DSB test of the school-going children in the four study areas are shown in the table no.3.29. The mean scores of Executive Function of school-going children of the three exposed and background areas were found to decrease with increasing pollution levels. The decreasing order of mean scores of Executive Function in the four study areas was: BA>LPA>MPA>HPA. The mean score of Executive Function on DSB test was highest in case of background area (2.86) and lowest in HPA (2.14) as also shown in figure no. 3.15.

Table no. 3.29. Mean scores of DSB of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
2.86	0.13	2.64	0.14	1.78	0.15	1.3	0.14	2.14	0.08

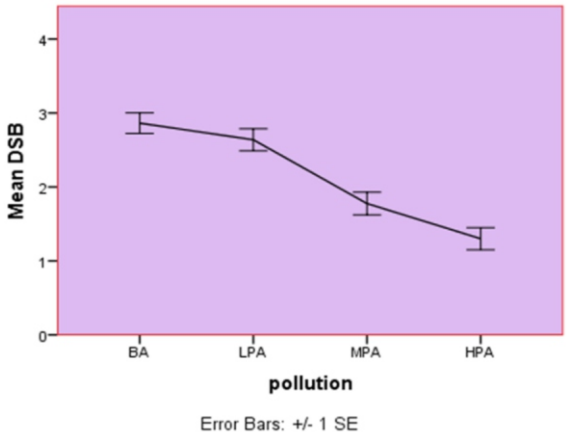


Figure no.315.. Means Plot of Working Memory (DSBscores) of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Executive Function/ DSB of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be significant (F=24.59, p<0.01) as revealed by the analysis of variance (Table no.3.30). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Executive Function/ DSB of school-going children of exposed area and background area' was rejected.

Table no. 3.30. ANOVA of DSB scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	128.66	42.89	24.59**
Within Groups	316	551.23	1.74	
Total	319	679.89		

The lower performances on Digit Span Backward (DSB) test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Digit Span Backward test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.31. Prevalence of lower performances on DSB test/ Executive Function among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	4	5	1	0
LPA (n=80)	10	12.5	11.3(7.9**)	2.08-61.11
MPA (n=80)	22	27.5	30(22.4**)	7.32-122.52
HPA (n=80)	37	46.25	68(44.7**)	19.74-234.07

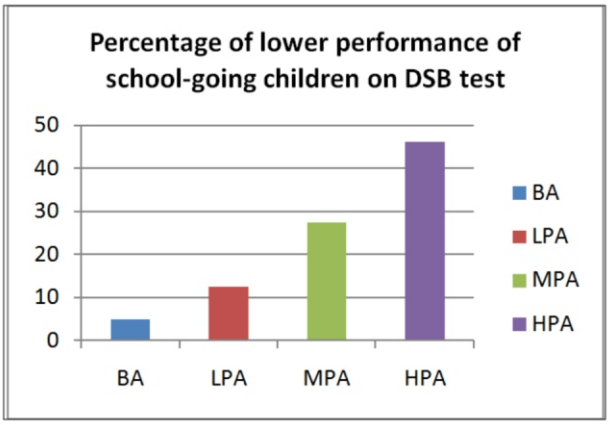


Figure no. 3.16. Prevalence (Percentage) of lower performance on digit span backward (DSB) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

A greater percentage of school-going children showed lower performance on DSB test in all the three exposed areas, low, moderate and high (12.5%, 27.5%, 46.25% respectively) polluted areas as compared to the background area (5%).

The higher prevalence of lower performance as compared to the background area, was statistically significant in moderate and high pollution exposed areas (BA vs MPA, OR=7.2, $p<0.01$; BA vs HPA, OR=16.3, $p<0.01$) as shown in the table no. 3.31

3.2.3.2.d. Vocabulary of School-going Children and Ambient Air Pollution

Verbal skills of school-going children were measured in terms of vocabulary knowledge of school-going children. Vocabulary test; a part of Stanford Binet's Test (SB Test) was used to assess the vocabulary knowledge of school-going children. The mean scores of Vocabulary test of the school-going children in the four study areas are shown in the table no.3.32. The mean scores of Vocabulary of school-going children of the three exposed and background areas were found to decrease with increasing pollution levels.

The decreasing order of mean scores of Vocabulary in the four study areas was: BA>LPA>MPA>HPA. The mean score of Vocabulary was highest in case of background area (7.61) and lowest in HPA (5.64) as also shown in figure no.3.17

Table no. 3.32. Mean scores of Vocabulary of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
7.61	0.29	6.14	0.21	5.9	0.24	5.64	0.31	6.32	0.14

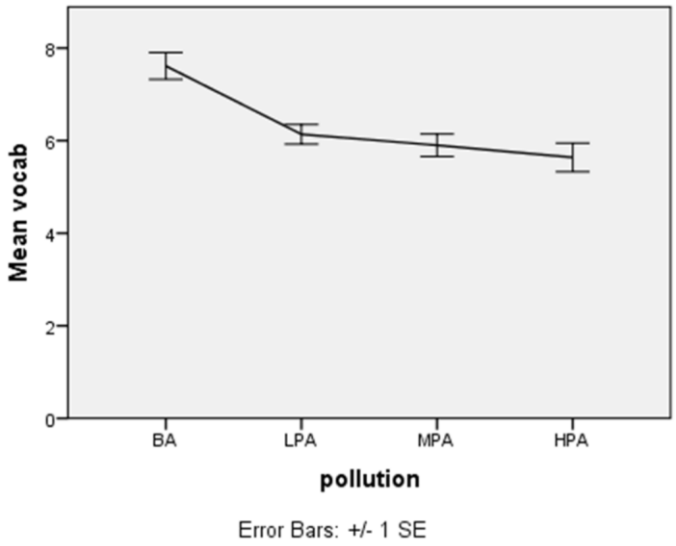


Figure no.317.. Means Plot of Vocabulary scores of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Vocabulary of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be significant (F=10.97, p<0.01) as revealed by the analysis of variance (Table no.3.33). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Vocabulary of school-going children of exposed area and background area' was rejected.

Table no. 3.33. ANOVA of vocab. scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	187.68	62.56	10.97**
Within Groups	316	1802.16	5.70	
Total	319	1989.85		

The lower performances on Vocabulary test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Vocabulary test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.34. Prevalence of lower performances on Vocabulary test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	3	3.75	1	0
LPA (n=80)	14	17.5	5.4(7.9**)	1.76-17.66
MPA (n=80)	16	20	6.4(10.1**)	1.03-4.0
HPA (n=80)	18	22.5	7.4(12.3**)	2.42-22.85

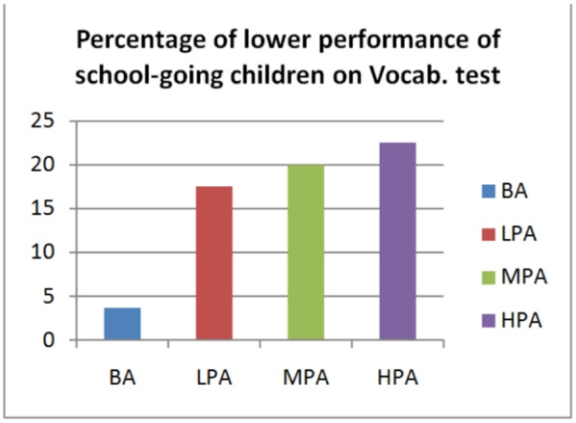


Figure no. 3.18. Prevalence (Percentage) of lower performance on Vocabulary test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

A greater percentage of school-going children showed lower performance on vocabulary test in all the three exposed areas, low, moderate and high (17.5%, 20%, 22.5% respectively) polluted areas as compared to the background area (5%). The higher prevalence of lower performance as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=5.4, $p<0.01$; BA vs MPA, OR=6.4, $p<0.01$; BA vs HPA, OR=7.4, $p<0.01$) as shown in the table no. 3.34.

3.2.3.2.e. Visuo-spatial Ability of School-going Children and Ambient Air Pollution

Block Design (A part of Malin's Test) was used to measure the Visuo-spatial ability of school-going children. The mean scores of Visuo-spatial ability/

Block Design test of the school-going children in the four study areas are shown in the table no.3.35. The mean scores of Visuo-spatial ability of school-going children of the three exposed and background areas were found to decrease with increasing pollution levels. The decreasing order of mean scores of Visuo-spatial ability in the four study areas was: BA>LPA>MPA>HPA. The mean score of Visuo-spatial ability was highest in case of background area (26.84) and lowest in HPA (18.54) as also shown in figure no.3.19.

Table no.3.35. Mean scores of Visuo-spatial Ability/ Block Design (BD) Test of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
26.84	1.06	21.93	0.97	20.65	1.13	18.54	1.28	21.99	0.58

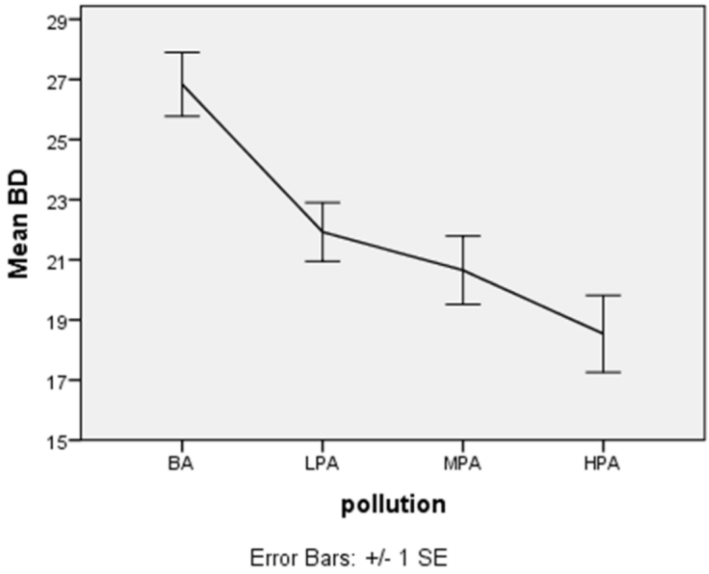


Figure no.3.19. Means Plot of Visuo-spatial Ability (Block Design scores) of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Visuo-spatial ability/ Block Design test of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be significant ($F=9.88$, $p<0.01$) as revealed by the analysis of variance (Table no.3.36). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Visuo-spatial ability/ Block Design test of school-going children of exposed area and background area' was rejected.

Table no. 3.36. ANOVA of BD scores of school-going children of different pollution levels

	Df	Sum of Squares	Mean Square	F
Between Groups	3	2977.43	992.47	9.88**
Within Groups	316	31742.53	100.45	
Total	319	34719.95		

***: p<0.01*

The lower performances on Block Design test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Block Design test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.37. Prevalence of lower performances on Block Design test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	4	5	1	0
LPA (n=80)	12	15	3.35(4.44*)	1.08-10.32
MPA (n=80)	16	20	4.75(8.22**)	1.63-13.77
HPA (n=80)	25	31.25	8.63(18.57**)	3.23-23.02

**: p<0.05, ** : p<0.01*

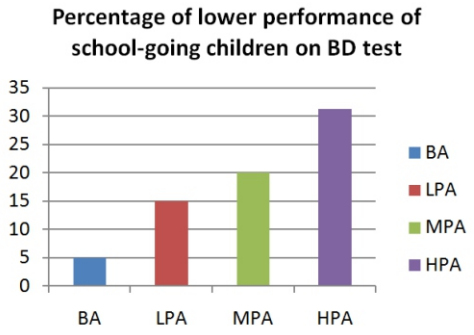


Fig. 3.20

A greater percentage of school-going children showed lower performance on Block Design test in all the three exposed areas, low, moderate and high (15%, 20%, 31.25% respectively) polluted areas as compared to the background area (5%). The higher prevalence of lower performance as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=3.35, p<0.01; BA vs MPA, OR=4.75, p<0.01; BA vs HPA, OR=8.63, p<0.01) as shown in the table no. 3.37.

Three kinds of memory; delayed recall, immediate recall, and recognition memories of school-going children were assessed using PGI memory sub-tests.

3.2.3.2.f. Delayed Recall Memory of School-going Children and Ambient Air Pollution

The mean values of delayed recall memory of the school-going children in the four study areas are shown in the table no.3.38. The mean scores of

delayed recall memory of school-going children of the two pollution exposed areas; high and moderate pollution areas and background areas were found to decrease with increasing pollution levels. However, the mean score of DR of school going children in low pollution area was more than the mean score of DR of school going children in background area. Thus, the increasing order of mean scores of delayed recall memory in the four study areas was: HPA<MPA<BA<LPA. The mean score of delayed recall memory was highest in case of Low Pollution area, LPA (8.23) and lowest in HPA (7.4) as also shown in figure no. 3.21

Table no. 3.38. Mean scores of DR of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
7.83	0.23	8.23	0.27	7.69	0.25	7.4	0.3	7.78	0.13

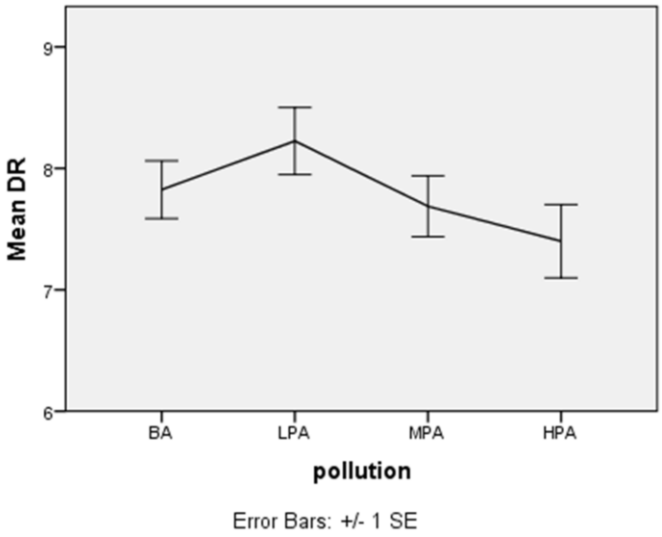


Figure no.3.21. Means Plot of Delayed Recall (DR) memory scores of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Delayed Recall Memory test of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be non-significant (F=1.64, p>0.05) as revealed by the analysis of variance (Table no.3.39). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Delayed Recall Memory test of school-going children of exposed area and background area' was accepted.

Table no.3.39. ANOVA of DR scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	28.23	9.41	1.64 (NS)
Within Groups	316	1809.89	5.73	
Total	319	1838.12		

NS: Non-significant

The lower performances on Delayed Recall Memory test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Delayed Recall Memory test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.40. Prevalence of lower performances on Delayed Recall test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	1	1.25	1	0
LPA (n=80)	4	5	4.15(1.85 NS)	0.53-32.26
MPA (n=80)	5	6.25	5.26(2.77 NS)	0.74-37.25
HPA (n=80)	8	10	8.7(5.7*)	1.49-51.66

**: $p<0.05$; NS: Non-significant*

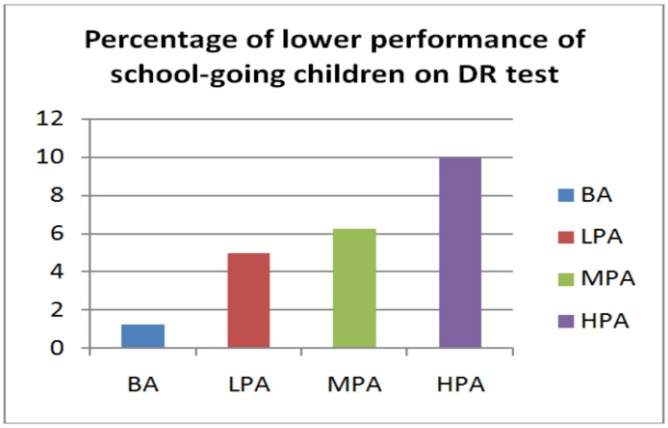


Figure no. 3.22. Prevalence (Percentage) of lower performance on delayed recall (DR) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

As shown in the table no. 3.40, a greater percentage of school-going children revealed lower performance on Delayed Recall Memory test in all three exposed areas; low, moderate and highly polluted areas (5%, 6.25% & 10% respectively) as compared to the background area (1.25%). However, the higher prevalence of lower Delayed Recall performance in school-going children exposed to low and moderate pollution areas as compared to the background area could not attain statistical significance ($p>0.05$) as shown in the table 3.40. The higher prevalence of lower Delayed Recall performance in school-going children exposed to high pollution area as compared to the background area was found to be statistically significant (BA vs HPA, OR=8.7, $p<0.01$).

3.2.3.2.g. Immediate Recall Memory of School-going Children and Ambient Air Pollution

The mean values of immediate recall memory of the school-going children in the four study areas are shown in the table no.3.41. The mean scores of immediate recall memory of school-going children of the three exposed and background areas were found to decrease with increasing pollution levels. The decreasing order of mean scores of immediate recall memory in the four study areas was: BA>LPA>MPA>HPA. The mean score of immediate recall memory was highest in case of background area (8.74) and lowest in HPA (4.98) as also shown in figure no. 3.23

Table no.3.41. Mean scores of IR of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
8.74	0.39	7.79	0.46	6.91	0.49	4.98	0.44	7.1	0.23

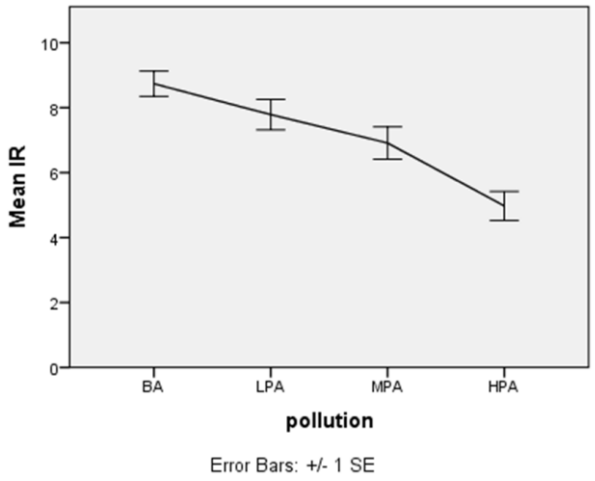


Fig. no.3.23. Means Plot of Immediate Recall (IR) memory scores of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Immediate Recall Memory test of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be significant (F=12.52, p<0.01) as revealed by the analysis of variance (Table no.3.42). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Immediate Recall Memory test of school-going children of exposed area and background area' was rejected.

Table no.3.42. ANOVA of IR scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	616.38	205.46	12.52**
Within Groups	316	5187.21	16.42	
Total	319	5803.60		

**: *p< 0.01*

The lower performances on Immediate Recall Memory test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Immediate Recall Memory test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.43. Prevalence of lower performances on Immediate Recall test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	1	1.25	1	0
LPA (n=80)	8	10	8.8(5.8*)	1.5-51.7
MPA (n=80)	9	11.25	10.01(6.8**)	1.8-56.4
HPA (n=80)	12	15	13.9(10.13**)	2.8-70.6

**: *p<0.01*

A greater percentage of school-going children showed lower performance on Immediate Recall Memory test in all the three exposed areas, low, moderate and high (10%, 11.25%, 15% respectively) polluted areas as compared to the background area (1.25%). The higher prevalence of lower performance on Immediate Recall Memory test as compared to the background area, was

also statistically significant in all the three exposed areas (BA vs LPA, OR=8.8, p<0.05; BA vs MPA, OR=10.01, p<0.01; BA vs HPA, OR=13.9, p<0.01) as shown in the table no. 3.43.

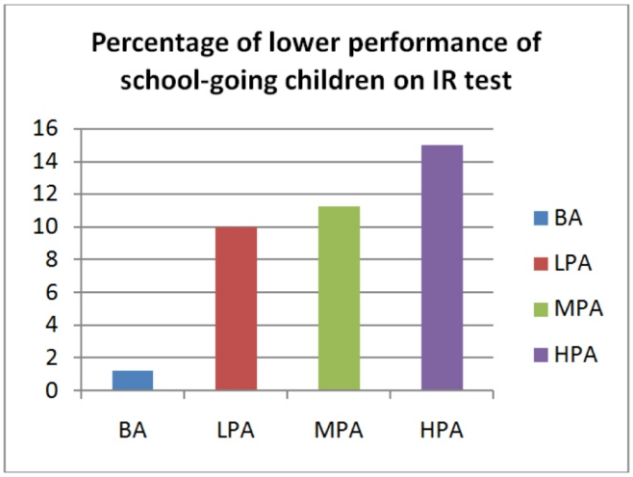


Figure no. 3.24. Prevalence (Percentage) of lower performance on Immediate Recall (IR) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

3.2.3.2.h. Recognition Memory of School-going Children and Ambient Air Pollution

The mean values of recognition memory of the school-going children in the four study areas are shown in the table no.3.44. The mean scores of recognition memory of school-going children of the moderate and high pollution exposed children were less than that of the school-going children of background areas. However, the mean score of recognition memory of school-going children of the low pollution exposed children was more than that of the school-going children of background areas. Thus, the increasing order of mean scores of recognition memory in the four study areas was: HPA<MPA<BA<LPA. The mean score of recognition memory was highest in case of low polluted area LPA (9.15) and lowest in HPA (8.65) as also shown in figure no.3.25.

Table no.3.44. Mean scores of RM of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
9	0.2	9.15	0.2	8.85	0.26	8.65	0.18	8.91	0.1

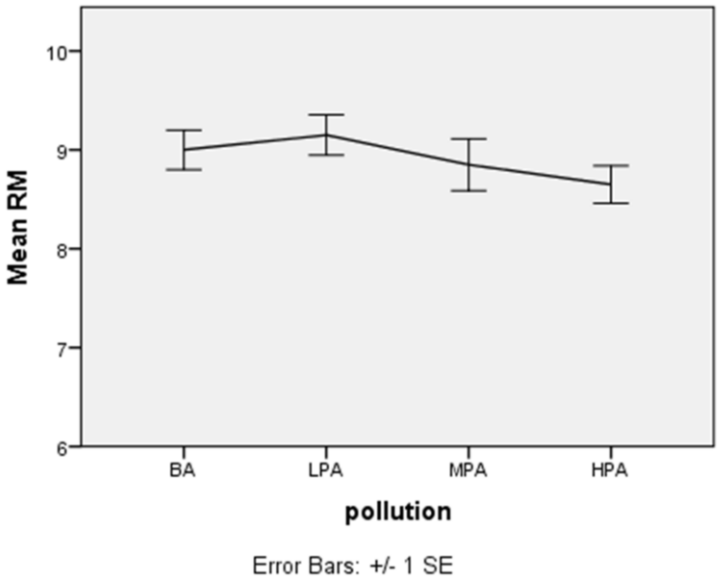


Figure no.3.25. Means Plot of Recognition Memory (RM) scores of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Recognition Memory test of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be non-significant (F=0.98, p>0.05) as revealed by the analysis of variance (Table no.3.45). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Recognition Memory test of school-going children of exposed area and background area' was accepted.

Table no.3.45. ANOVA of RM scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	10.95	3.65	0.98(NS)
Within Groups	316	1174.60	3.72	
Total	319	1185.55		

NS: Non-significant

The lower performances on Recognition Memory test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Recognition Memory test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.46. Prevalence of lower performances on Recognition Memory test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	0	0	1	0
LPA (n=80)	6	7.5	0	0
MPA (n=80)	9	11.25	0	0
HPA (n=80)	9	11.25	0	0

As shown in the table no. 3.26 none of the school-going child in the background area revealed lower performance on recognition memory test. Hence, the odds ratio of lower performance on recognition memory test in three exposed areas with respect to the background area could not be calculated.

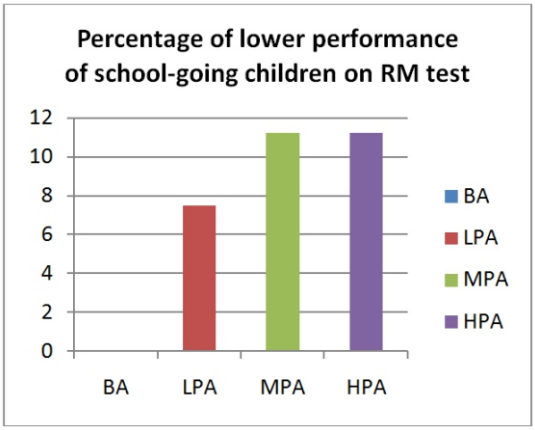


Figure no. 3.26. Prevalence (Percentage) of lower performance on Recognition Memory (RM) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

3.2.3.2.i. Perceptual Accuracy of School-going Children and Ambient Air Pollution

Coding; a part of Malin's test was used to measure the perceptual accuracy or vigilance of school-going children. The mean values of perceptual accuracy of the school-going children in the four study areas are shown in the table no.3.47. The mean scores of perceptual accuracy of school-going children of the three exposed and background areas were found to decrease with increasing pollution levels. The decreasing order of mean scores of perceptual accuracy in the four study areas was: BA>LPA>MPA>HPA. The mean score of perceptual accuracy was highest in case of background area (34.78) and lowest in HPA (27.99) as also shown in figure no.3.27

Table no.3.47. Mean scores of Perceptual Accuracy/ Coding Test of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
34.78	1.74	29.9	1.13	28.81	0.96	27.99	1.15	30.38	0.65

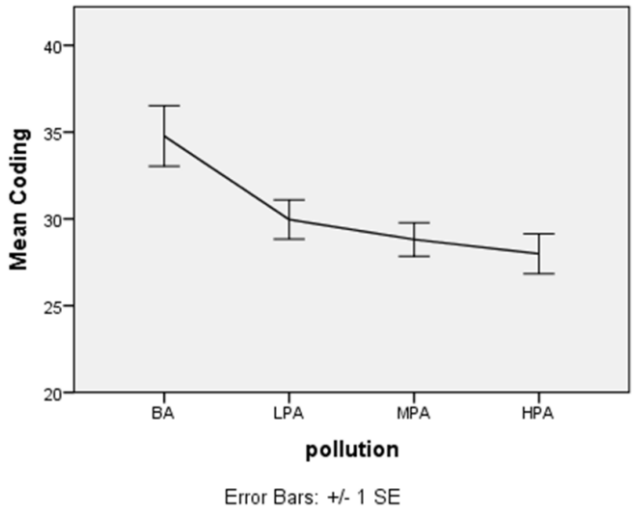


Figure no.3.27. Means Plot of Perceptual Accuracy (Coding Test scores) of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Perceptual Accuracy/ Coding test of the school-going children of three exposed (LPA, MPA, HPA) and background areas was found to be significant (F=5.61, p<0.01) as revealed by the analysis of variance (Table no.3.48). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Perceptual Accuracy/ Coding test of school-going children of exposed area and background area' was rejected.

Table no.3.48. ANOVA of Coding scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	2213.71	737.90	5.61**
Within Groups	316	41580.01	131.58	
Total	319	43793.72		

**: $p < 0.01$

The lower performances on Coding/ Perceptual Accuracy test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Coding test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.49. Prevalence of lower performances on Coding/ Perceptual Accuracy test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	3	3.75	1	0
LPA (n=80)	10	12.5	3.7(4.1*)	1.04-12.9
MPA (n=80)	12	15	4.5(5.6*)	1.3-15.2
HPA (n=80)	13	16.25	4.9(6.9*)	1.5-16.4

A greater percentage of school-going children showed lower performance on Coding/ Perceptual Accuracy test in all the three exposed areas, low, moderate and high (12.5%, 15%, 16.25% respectively) polluted areas as compared to the background area (3.75%). The higher prevalence of lower performance on Coding/ Perceptual Accuracy test as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=3.7, p<0.05; BA vs MPA, OR=4.5, p<0.05; BA vs HPA, OR=4.9, p<0.05) as shown in the table no. 3.54.

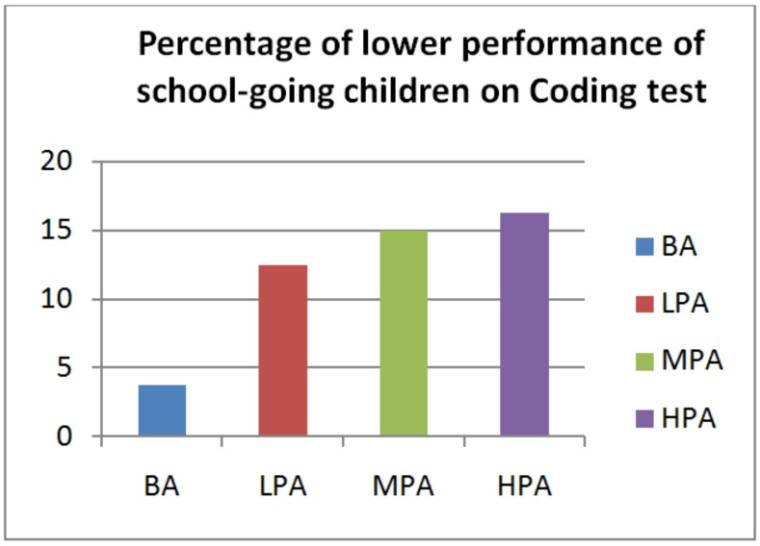


Figure no. 3.28.. Prevalence (Percentage) of lower performance on Coding (Perceptual Accuracy & Speed) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

Major Findings of Intelligence and its variables of School-going Children and Ambient Air Pollution:

1. The mean scores of most of the intelligence variables; full IQ, attention, executive function, vocabulary knowledge, visuo-spatial ability, immediate recall memory and processing speed & accuracy of school-going children of the three exposed areas and a background area were found to decrease with increasing pollution levels. The decreasing order of mean scores of all these intelligence variables of school-going children in the four study areas was: BA>LPA>MPA>HPA. Thus, the mean scores of all these intelligence variables of school-going children were highest in case of background area (BA) and lowest in HPA.

2. Analysis of variance revealed that the difference between mean values of all the above mentioned intelligence variables; full IQ, attention, executive function, vocabulary knowledge, visuo-spatial ability, immediate recall memory and processing speed & accuracy of school-going children of exposed areas and background area were found to be significant.

3. Only in case of two intelligence variables; delayed recall memory and recognition memory, the decreasing order of mean scores of all these intelligence variables of school-going children in the four study areas was: LPA>BA>MPA>HPA. Thus, the mean scores of all these intelligence variables of school-going children were highest in case of children exposed to LPA and lowest in case of children exposed to HPA.

4. Analysis of variance revealed that the difference between mean values of the two intelligence variables; delayed recall memory and recognition memory of school-going children of exposed areas and background area were found to be non-significant.

5. On calculating the prevalence of lower performance on different intelligence test variables among school-going children of different pollution level areas, it was observed that in case of most of the intelligence variables; full IQ, attention, executive function, vocabulary knowledge, visuo-spatial ability, immediate recall memory, delayed recall memory and processing speed & accuracy of school-going children of the three exposed areas the prevalence of lower performance was greater than that of the school-going children of the background area. These differences between the prevalence of lower

performances in school-going children of the three exposed areas and that of the preschoolers of the background area were found to be significant except in case of 'attention' and 'delayed recall'.

The difference between the prevalence of lower performance of the school-going children of the low pollution exposed area (LPA) and that of the background area on items of DSF or 'attention' was found to be non-significant.

The difference between the prevalence of lower performance of the school-going children of the LPA & MPA and that of the background area on items of 'Delayed Recall Memory' was found to be non-significant.

Discussion of Results:

As the child grows from preschool age (3-6 years) to school-going age (7-12 years), his/ her neuropsychological (cognitive and motor) abilities play an important role in determining his/ her performance; curricular as well as co-curricular activities in school (Deary et al. 2007; Fergusson et al. 2005; Neisser et al. 1996) and the performance in the society; the life skills i.e., the social and moral maturity. Higher childhood IQ scores have been found to be associated with higher educational achievement and more positive outcomes throughout life course (Braaten and Norman 2006). Environmental exposures may disproportionately influence the cognitive development of children growing up in disadvantaged or lower socio-economic environments (Row et al 1999; Turkheimer et al. 2003). In the present study, the ambient air pollution exposure was found to be adversely affecting almost all the cognitive measures; full IQ, attention, executive function, vocabulary knowledge, visuo-spatial ability, immediate recall memory and processing speed & accuracy of school-going children of upper-lower SES (Kuppuswamy Scale) families except delayed recall and recognition memory.

Specifically children of government primary schools of various study areas were considered as the students of the lower income group are found to be more at risk of health hazards associated with local air pollution and other deprived conditions (Adamkiewicz et al. 2011; Hutch et al. 2011; Jackson and Tester.2008; Ou et al. 2008). The classrooms inside the government schools were found to be very airy and well ventilated leading to an assumption that the air quality inside the classrooms might be at par with the air quality outside. Out of the six hours of school timings, for about

three hours, the children were found to be engaged in classroom activities and half of the time the children were mostly involved in outdoor activities. The outdoor play area in most of the schools was more than half of the total area of the school. The ambient air quality inside the school boundary was thus very much similar to the AAQ of the nearby areas. The physical activity of children at school may be increased due to physical education and play activities and their breathing rates and dose of inhaled pollutants may increase during school hours (McConnell et al. 2010). Moreover, a school's proximity to industries was reported to be significantly and negatively associated with lower aggregate standardized test scores in certain studies (Legot etal, 2011; Lucieret al, 2011; Scharber etal, 2013).

Several studies have been reviewed and found to support the outcomes of the present study. Calderon G. etal. (2008 and 2011) in his studies investigated the effects of ambient air pollution of Mexico city on cognitive functions in children. The cognitive functions of children were measured by the Weschler Intelligence Scale for Children-Revised. Residency in a highly exposed area was significantly associated with cognitive deficit. A prospective cohort study (Sunyer J. 2015) was conducted to examine the effects of traffic related air pollution (TRAP) on cognitive development among 2715 children aged 7-10 years from 39 schools in Barcelona. The study reported smaller growth in cognitive development in children at schools highly exposed to TRAP than low exposed schools. Children at schools highly exposed to elemental carbon (EC), NO2, ultrafine particulate matter (UFP) had smaller improvements in all the cognitive parameters. Grineski et al (2016) also conducted a cross-sectional study to examine the impact of school-level exposures to hazarduous air pollutants (HAPs) on academic performance at fourth and fifth grade children in the EI Paso (Texas, USA). HAP exposures at school were found to be associated with lower individual level grade point.

Suglia et al (2008) examined the relationship between black carbon and cognitive functions among 202 children in Boston, Massachusetts. Cognitive functions were measured by the Kauffman Brief Intelligence Test (KBIT) and the Wide Range Assessment of Memory and Learning (WRAML). After adjustment for age, gender, primary language spoken at home, mother's education, birth weight, passive smoking and blood lead levels, BC exposure was associated with a decrease in scores of various cognitive measures.

In the present study, various aspects of intelligence; verbal as well as non-verbal (performance) intelligence were found to be adversely affected by the

AAP. Majority of the tests used in the study were non-verbal or performance tests. The results were found to be consistent with the outcome of study by Harris MH. et al, (2015). In comparison to children living >=200m from a major roadway at birth, those living <50m away had lower nonverbal IQ, somewhat lower verbal IQ and visuo-motor abilities. Scores on the block design test for visuospatial ability, a non-verbal/ performance test were found to be affected by AAP in our study also.

In addition to visuospatial ability, mean scores on other non-verbal tests like digit span forward and backward (attention and executive function) and coding (perceptual accuracy) tests of school-going children were also found to be negatively affected by AAP. In another cross-sectional study on 861 children 8-9 years old by Wang et al (2009), exposure to traffic related air pollution (NO_2 & PM_{10}) was associated with poor performance in Visual Simple Reaction Time, Continuous Performance, Digit Symbol, Pursuit Aiming and Sign Register Assessments.

Coding, a test which involves processing of mental representations with speed and accuracy was found to be affected among the school-going children by the neurotoxicity of particulate matter (PM_{10}). The odds of getting lower performance on perceptual accuracy test among the school-going children as compared with the background / clean area were found to be 3.7, 4.5 and 4.9 times higher in low, moderate and high polluted areas respectively. Thus, the risk of lower performance on coding test among school-going children was found to be associated with PM_{10} exposure.

Calderon G. (2008b), in an autopsy study reported presence of particulate matter in perivascular tissues of the frontal cortex in otherwise normal children and young adults who died from accidents. Histological changes in the brain due to the AAP were found to be consistent with neuroinflammation. Calderon G. (2008) also reported evidence of brain parenchymal changes on MRI (magnetic resonance imaging) and significant deficits in cognition, memory and executive function in children exposed to high levels of ambient air pollution compared with low-exposure matched controls.

In consistence with the above findings, the mean scores of school-going children of various exposed areas on attention (digit span forward), executive function or working memory (digit span backward) and immediate recall memory tests (PGI Memory test) were found to be inversely affected by exposure to particulate matter (PM_{10}) in our study. Particulate matter (PM_{10}) exposure was reported to be associated with inattentiveness and impulsivity

characters found in children suffering from ADHD in a cross-sectional study. 9-17 years old (n=1819) in India were studied for the impact of traffic related air pollution on ADHD in the study (Siddique et al, 2011). In another study, Newman et al (2013) explored the association between early life exposure to elemental carbon attributed to traffic (ECAT) and ADHD symptoms at 7 years of age. Compared with children exposed to ECAT <0.40 $\mu g/m^3$ during their first year of life, children with high ECAT exposure were 70% more likely to have a high hyperactivity score after adjustment for potential confounders with a slightly stronger association among children whose mothers had more than a high school education. Elemental carbon is supposed to be an important component of particulate matter. Both the studies are thus supporting the results of the present study.

The various types of memories tested in the present study may be divided into three; sensory, short-term and long-term memories. The sensory memory is further divided into two; the ichonic/ visual memory and echoic/ auditory memory. The sensory memories rely heavily on the visual and auditory receptor neurons in the brain. Similar to our results of 'visual cognizance' during infancy stage, the visual / iconic memory of school-going children which was assessed through the Recognition Memory Test (part of PGI memory test) was found to reveal no significant difference in various areas due to the AAP. ANOVA as well as chi-square tests both revealed no significant differences in the performance of school-going children of various exposed and background areas on the recognition memory test. The test in which the task was to simply identify simple objects like keys, book, house etc. in the second card, visually observed in the first card. The results were found to be in consistence with the findings of Harris MH. et al (2015). Design memory and picture memory scores measured by WRAML2 test did not differ substantially by major roadway proximity (TRAP) among children of 7 to 10 years of age in the study by Harris MH et al.

However, in case of immediate recall memory, unlike the results of preschool stage, but somewhat similar to the results of infancy stage (no clear distinction between low, moderate and high pollution exposed children), the immediate recall memory of school-going children of various exposed and background area measured by a sub-test of PGI memory test, a clear, distinctive and highly significant difference was observed through ANOVA as well as chi-square test.

Immediate recall or short term memory is limited to about four chunks of information and supposed to last for about 250 millisecond whereas, the

delayed recall memory has a larger capacity and lasts for decades (Kellogg, RT. 2007 sage pub). Thus, the delayed recall memory is known to play an important role in learning for academic achievement as well as perfection in life skills for the school-going children. In the present research work, in contrast to immediate recall memory of school-going children, delayed recall memory of school-going children showed no significant difference in the exposed areas and clean area through ANOVA ($p>0.05$). Murre, JMJ (2013) and Vogel Mc, Collough & Machizava, (2007) in their studies reported that delayed recall memory does not always have a strong correlation with immediate recall memory. Certain factors such as individual differences in neuromodulators like acetylcholine and dopamine could affect long term memory more than short term memory.

However, the percentage of lower performance on delayed recall test was found to be more in the exposed areas; LPA, MPA & HPA as compared to clean area. But, it could gain significant difference only in case of HPA and BA. The odds of lower performance on delayed recall test in HPA exposed school-going children were 8.7 times higher as compared to the school-going children in BA/ clean area.

Manual Dexterity of School-going Children and Ambient Air Pollution

Pins and board test scores were utilized as the indicators of manual dexterity of school-going children in the present study. Three kinds of manual dexterity of school-going children; right hand, left hand and both hand dexterity was measured using pins and board test.

3.2.3.2.j. Right Hand Dexterity of School-going Children and Ambient Air Pollution

The mean values of Right Hand Dexterity of the school-going children in the four study areas are shown in the table no.3.50. The mean scores of Right Hand Dexterity of school-going children of the two exposed areas; moderate and highly pollution exposed and the background area were found to decrease with increasing pollution levels. However, the mean scores of RHD of children in the low pollution exposed area was found to be less than the mean scores of RHD of children in the moderate pollution exposed area Thus, the increasing order of mean scores of perceptual accuracy in the four study areas was: HPA<LPA<MPA<BA. The mean score of perceptual accuracy was highest in case of background area (27.6) and lowest in HPA (22.31) as also shown in figure no.3.29.

Table no.3.50. Mean scores of RHD of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
27.6	0.51	24.64	0.35	24.94	0.53	22.31	0.57	24.87	0.27

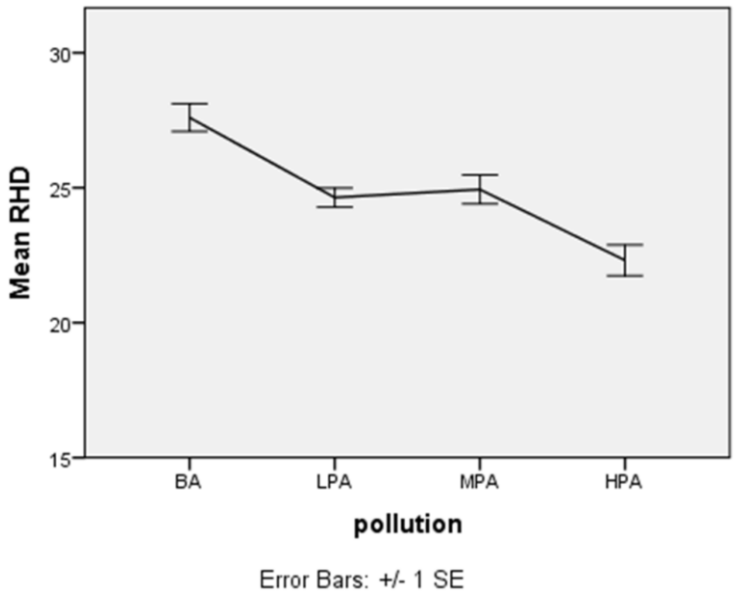


Figure no.3.29. Means Plot of Right Hand Dexterity (RHD) scores of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Right Hand Dexterity test of the school-going children of three exposed areas (LPA, MPA, HPA) and that of background area was found to be significant ($F=18.72$, $p<0.01$) as revealed by the analysis of variance (Table no.3.51). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Right Hand Dexterity test of school-going children of exposed area and background area' was rejected.

Table no.3.51. ANOVA of RHD scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	1124.18	374.73	18.72**
Within Groups	316	6325.56	20.02	
Total	319	7449.75		

The lower performances on Right Hand Dexterity test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Right Hand Dexterity test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.52. Prevalence of lower performances on Right Hand Dexterity (RHD) test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	3	3.75	1	0
LPA (n=80)	10	12.5	3.6(4.1*)	1.04-12.9
MPA (n=80)	11	13.75	4.1(5.0*)	1.19-14.05
HPA (n=80)	20	25	8.5(14.6**)	2.85-25.65

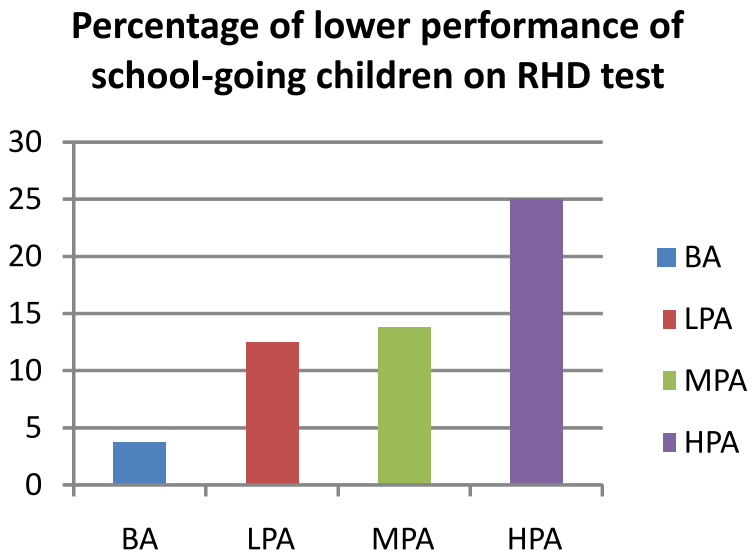


Figure no. 3.30. Prevalence (Percentage) of lower performance on right hand dexterity (RHD) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

A greater percentage of school-going children showed lower performance on Right Hand Dexterity test in all the three exposed areas, low, moderate and high (12.5%, 13.75%, 25% respectively) polluted areas as compared to the background area (3.75%). The higher prevalence of lower performance on Right Hand Dexterity test as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=3.6, $p<0.05$; BA vs MPA, OR=4.1, $p<0.05$; BA vs HPA, OR=8.5, $p<0.01$) as shown in the table no. 3.52.

3.2.3.2.k. Left Hand Dexterity of School-going Children and Ambient Air Pollution

The mean values of Left Hand Dexterity of the school-going children in the four study areas are shown in the table no.3.53. The mean scores of Left Hand Dexterity of school-going children of the three pollution exposed areas and the background area were found to decrease with increasing pollution levels. The decreasing order of mean scores of Left Hand Dexterity of school-going children in the four study areas was: BA>LPA>MPA>HPA. The mean score of Left Hand Dexterity of school-going children was highest in case of background area (22.44) and lowest in HPA (20.11) as also shown in figure no.3.31

Table no.3.53. Mean scores of LHD of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
22.44	0.5	19.98	0.39	19.49	0.4	18.53	0.55	20.11	0.24

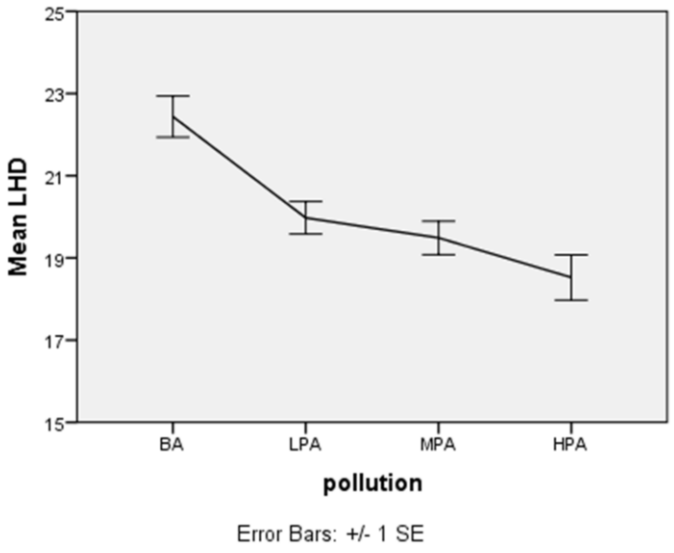


Figure no.3.31. Means Plot of Left Hand Dexterity (LHD) scores of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Left Hand Dexterity test of the school-going children of three exposed areas (LPA, MPA, HPA) and that of background area was found to be significant ($F=12.71$, $p<0.01$) as revealed by the analysis of variance (Table no.3.54). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Left Hand Dexterity test of school-going children of exposed area and background area' was rejected.

Table no.3.54. ANOVA of LHD scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	666.81	222.27	12.71**
Within Groups	316	5527.58	17.49	
Total	319	6194.39		

The lower performances on Left Hand Dexterity test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Left Hand Dexterity test in the three exposed groups as compared to the background/ control group was also calculated.

Table no. 3.55. Prevalence of lower performances on Left Hand Dexterity (LHD) test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
UA (n=80)	1	1.25	1	0
LPA (n=80)	9	11.25	10.01(6.8**)	1.8-56.4
MPA (n=80)	12	15	13.9(10.13**)	2.7-70.6
HPA (n=80)	17	21.25	21.3(16.02**)	4.7-95.3

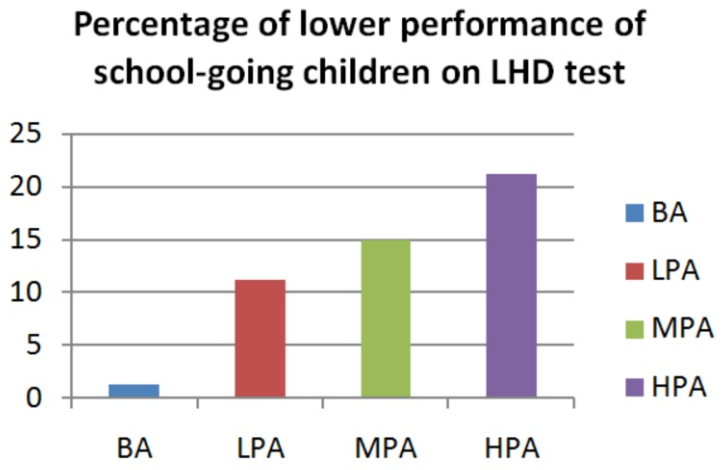


Figure no. 3.32. Prevalence (Percentage) of lower performance on left hand dexterity (LHD) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

A greater percentage of school-going children showed lower performance on Left Hand Dexterity test in all the three exposed areas, low, moderate and high (11.25%, 15%, 21.25% respectively) polluted areas as compared to the background area (1.25%). The higher prevalence of lower performance on Left Hand Dexterity test as compared to the background area, was also statistically significant in all the three exposed areas (BA vs LPA, OR=10.01, p<0.01; BA vs MPA, OR=13.9, p<0.01; BA vs HPA, OR=21.3, p<0.01) as shown in the table no. 3.60.

3.2.3.2.1. Both Hand Dexterity of School-going Children and Ambient Air Pollution

The mean values of Both Hand Dexterity of the school-going children in the four study areas are shown in the table no.3.56. The mean scores of Both Hand Dexterity of school-going children of the three pollution exposed areas and the background area were found to decrease with increasing pollution levels. The decreasing order of mean scores of Both Hand Dexterity of school-going children in the four study areas was: BA>LPA>MPA>HPA. The mean score of Both Hand Dexterity of school-going children was highest in case of background area (35.2) and lowest in HPA (30.29) as also shown in figure no.3.33.

Table no.3.56. Mean scores of BHD of school-going children of different pollution exposed and background areas

BA (n=80)		LPA (n=80)		MPA (n=80)		HPA (n=80)		Total (n=320)	
Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
35.2	0.62	33.06	0.43	32.45	0.74	30.29	1.03	32.75	0.38

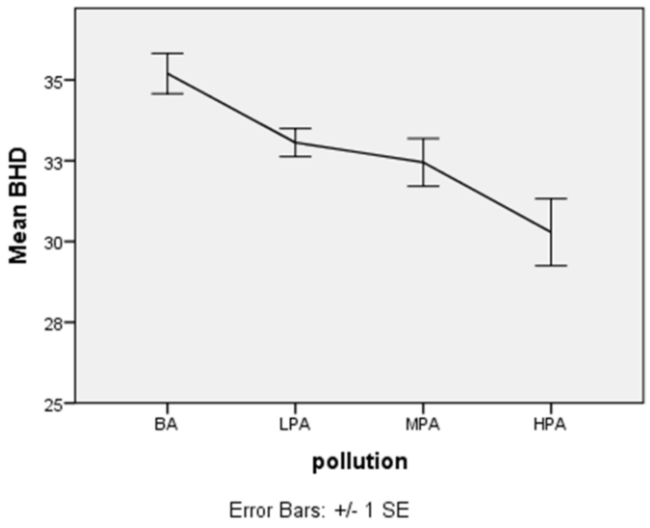


Figure no.3.33.. Means Plot of Both Hand Dexterity (BHD) scores of the school-going children (6-12 years) of different pollution exposed (LPA, MPA & HPA) and background areas (BA).

The difference between the mean scores of Both Hand Dexterity test of the school-going children of three exposed areas (LPA, MPA, HPA) and that of background area was found to be significant (F=7.42, p<0.01) as revealed by the analysis of variance (Table no.3.57). Thus, the null hypothesis that 'there will be no significant difference between the mean scores of Both Hand Dexterity test of school-going children of exposed area and background area' was rejected.

Table no. 3.57. ANOVA of BHD scores of school-going children of different pollution levels

	df	Sum of Squares	Mean Square	F
Between Groups	3	980.33	326.78	7.42**
Within Groups	316	13899.68	43.99	
Total	319	14880.00		

The lower performances on Both Hand Dexterity test in all the four study areas were counted and compared using chi-square test. The odds or the risk of getting lower performances on the Both Hand Dexterity test in the three exposed groups as compared to the background/ control group was also calculated.

Table no.3.58. Prevalence of lower performances on Both Hand Dexterity (BHD) test among the school-going children of different pollution exposed and background area.

Area	N	%	OR(χ2)	LCL-UCL (95% C.I.)
BA (n=80)	4	5	1	0
LPA (n=80)	11	13.75	3.02(3.6 NS)	0.9-9.5
MPA (n=80)	16	20	4.75(8.22**)	1.63-13.8
HPA (n=80)	24	30	8.14(17.31**)	3.03-21.9

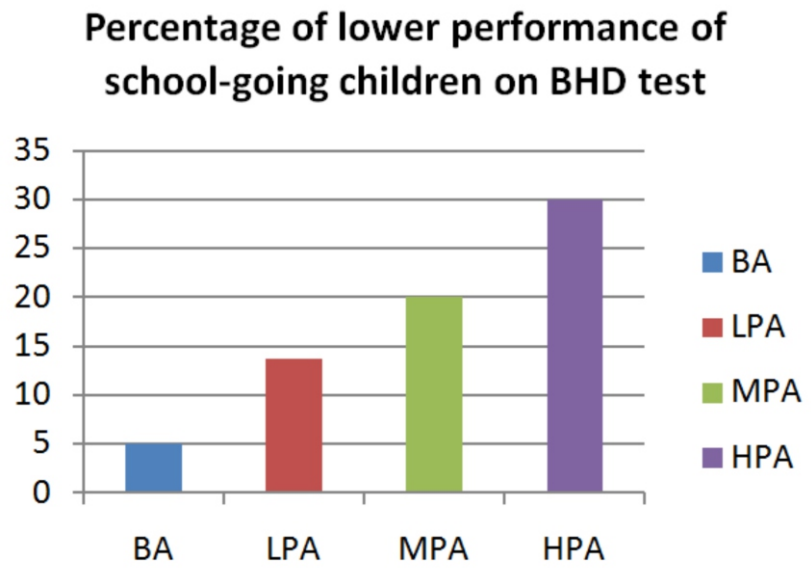


Figure no. 3.34.. Prevalence (Percentage) of lower performance on both hand dexterity (BHD) test among school-going children of different pollution exposed areas (LPA, MPA, HPA) and background area (BA)

As shown in the table no. 3.58, a greater percentage of school-going children revealed lower performance on Both Hand Dexterity test in all three exposed areas; low, moderate and highly polluted areas (13.75%, 20% & 30% respectively) as compared to the background area (5%). However, the higher prevalence of lower performance on the BHD in school-going children exposed to low pollution areas as compared to the background could not attain statistical significance ($p>0.05$) as shown in the table 3.58. The higher prevalence of lower performance on BHD in school-going children exposed to moderate and high pollution area as compared to the background area was found to be statistically significant (BA vs MPA, OR=4.75, $p<0.01$; BA vs HPA, OR=8.14, $p<0.01$).

Major Findings of Manual Dexterity of School-going Children and Ambient Air Pollution:

1. The mean scores of LHD and BHD of school-going children of the three exposed and background areas were found to decrease with increasing pollution levels. The decreasing order of mean scores of LHD and BHD of school-going children in the four study areas was: BA>LPA>MPA>HPA. Thus, the mean scores of LHD & BHD were highest in case of background area (BA) and lowest in HPA.
2. The decreasing order of mean scores of RHD of school-going children in the four study areas was: BA>MPA>LPA>HPA. Thus, the mean

score of RHD was highest in case of background area (BA) and lowest in HPA.

3. The difference between mean values of all three dexterities; RHD, LHD and BHD of school-going children of exposed areas and background area was found to be significant through analysis of variance.

4. Prevalence of lower performance on manual dexterity test (RHD, LHD, BHD) in school-going children exposed to low, moderate and high pollution was found to be higher in comparison to school-going children in background area. The difference between lower performance of school-going children on RHD, LHD, BHD of the three exposed area and that of the school-going children in background area was found to be significant, except in case of BHD of school-going children of LPA.

Discussion of Results:

Consistent with the findings of Haenninen (1978), dela Burde et al (1995), Sinha (1995), Guxens et al. (2014), Friere et al (2016), the use of finer muscles in motor coordination was found to be inversely and significantly affected by exposure to ambient air pollution. All three kinds of manual dexterity; right hand, left hand and both hand of preschoolers were observed to be equally affected by the AAP. Friere et al (2016) in a cohort study found that children exposed to higher ambient air NO2, compared to their counterparts, had a statistically significant decrease of 8.61 points in gross motor score. Guxens et al (2014) investigated a negative association between prenatal air pollution, especially NO_2 and psychomotor development in children aged 1-6 years. About 9482 children were studied within six prospective cohort studies. The concentration of air pollution was calculated using land use regression models, air monitoring campaigns and back-extrapolation procedure.

Apart from human studies several studies conducted on rodents like mice reveal that developmental exposure to numerous toxic pollutants may interfere with developmental processes of the nervous system. Although there are differences between the rodent and human brain, certain analogous structures can be identified. Moreover, the ontogeny of specific behaviours can be used to draw inferences regarding the maturation of certain brain structures in rodents and humans (Rice, D. and Barone S, 2000). These animal observations expand the observations in humans and are suggestive of the underlying mechanisms. In a postmortem study of Mexico City, neuropathological lesions in the prefrontal cortex similar to

neurodevelopmental and/ or neurodegenerative diseases were observed in both dogs and children exposed to Mexico City air pollution (L.Calderon GL et al, 2008). In several other animal studies, i*n utero* exposure to high levels of diesel exhaust were found to cause alterations in motor activity, motor coordination in male mice (S.Yokota et al, 2013; T.Suzuki et al, 2010).

As the child enters school-going age, the predominance for use of one hand either right or left becomes more evident. Thus, the higher mean scores of RHD as compared to LHD reveal the general trend of preference of use of right hand over left hand among the school-going children.

The results of the present study are consistent with the results of Sinha (1995) who studied 960 school going children of road side area, industrial area, commercial area and remote residential area of Agra City to explore the neurotoxic effects of ambient air pollution (lead) on their psychomotor behaviour. The concentration of lead in hair of children of different areas was estimated using Atomic Absorption Spectrometer. Bender Gestalt test for visual-motor performance, finger tapping test and finger dexterity test were used to measure the motor performance of the children. The hair lead levels of children residing and schooling in the areas with high pollution were found to be higher than children living and studying in commercial and remote areas. The psychomotor behaviour and visuomotor behaviour of children were also affected by the levels of lead toxicity present in their bodies.

Multiple regression analysis between neuropsychological variables and intervening family variables of school-going children:

After studying the effect of independent variable AAP (ambient air pollution) on different neuropsychological variables of school-going children, the effect of intervening socio-demographic factors like SES, gender and family size on different neuropsychological variables of school-going children were studied. The pearson correlation co-efficient between various neuropsychological variables and the socio-demographic variables were obtained. The correlation coefficients are depicted in table no.3.59.

Table no. 3.59. Correlations of neuropsychological variables (DVs) of school-going children (7-12 yrs) with pollution and family variables (Ivs)

Neuropsychological Variables	Pollution	CA	Gender	SES	FamilySize
IQ	-.396**	.066	.014	.127*	.002
Attention/ DSF	-.348**	.228**	.065	.031	.084
Executive Function/ DSB	-.426**	.255**	.168**	.297**	-.032
Vocabulary	-.276**	.294**	.171**	.226**	.110*
Visuo-spatial Ability/ BD	-.281**	.506**	.163**	.145**	.144*
Delayed Recall	-.085	.143*	.011	.084	.040
Immediate Recall	-.319**	.207**	.123*	.183**	.069
Recognition Memory	-.078	.190**	.097	.111*	.152**
Perceptual Accuracy/ Coding	-.206**	.269**	.042	.212**	.003
RHD	-.361**	.504**	.035	.180**	.035
LHD	-.311**	.429**	.051	.075	.104
BHD	-.252**	.358**	.075	.159**	.052

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The obtained correlation coefficients revealed that there was a negative association between all the mean scores of various neuropsychological variables and PM10. With increasing levels of PM10/ AAP, the scores on various neuropsychological tests were found to decrease. This inverse relationship between the level of PM10 and various neuropsychological variables was revealed through the analysis of variance also.

Further to calculate the percentage/ proportion of variance due to AAP and other personal & family variables, the multiple regression analysis was performed.

For carrying out multiple regression analysis, AAP was taken as main predictor variable and the other important covariates affecting the neuropsychological performances of children were age, gender, SES and family size. These covariates were also treated as predictor variables and twelve neuropsychological measures were taken as criterion or dependent variable. List of these variables is given below in table no.3.60.

Table no.3.60. List of Predictor and Criterion Variables for Multiple Regression Analysis

Predictor or Independent Variables	Criterion or Dependent Variables
1.Ambient air pollution	1.Full IQ
2.Chronological age	2.Attention (DSF)
3.Gender	3.Working Memory (DSB)
4.SES	4.Vocabulary
5.Family size	5.Visuo-spatial Ability
	6.Immediate Recall Memory
	7.Delayed Recall Memory
	8.Recognition Memory
	9.Perceptual Accuracy
	10.RHD
	11.LHD
	12.BHD

For interpreting the results obtained from the multiple regression analyses (Table no. 3.61), the variance caused by the combined effect of total predictor variables is depicted by obtained R Square value, which is further adjusted (after adjusting chance errors) into Adjusted R Square value. Individual contribution of each predictor variable can be noted with the help of Beta weights. The independent/ predictor variables showing a significant correlation ($p<0.01$) (Table no. 3.59) with various neuropsychological variables have been depicted in the multiple regression table (Table no.3.61). Levels of significance indicated in the table (3.61) against each predictor variable show the extent of significance in predicting the variance caused in the neuropsychological/ dependent variable. Further, to calculate the proportion of variance caused by each variable individually, beta weight of each predictor variable was multiplied by their respective correlation coefficients.

Table no. 3.61. Multiple Regression Analysis examining the association between Independent variables (predictor variables) and neuropsychological variables (criterion/ dependent variables)

Neuropsychological Variable (Criterion Variables)	Personal & Family Variable (Predictor Variables)	R Square[a]	Adjusted R Square[a]	Beta	p-value
DSF	pollution	.178	.165	-.345	.000
	CA			.212	.000
DSB	pollution	.337	.326	-.406	.000
	CA			.235	.000
	Gender			.177	.000
	SES			.240	.000
Vocabulary	pollution	.227	.215	-.256	.000
	CA			.270	.000
	Gender			.187	.000
	SES			.166	.001
BD	pollution	.374	.364	-.260	.000
	CA			.486	.000
	Gender			.191	.000
Immediate Recall	pollution	.179	.166	-.305	.000
	CA			.186	.000
	Gender			.140	.007
	SES			.129	.013
RM	CA	.077	.062	.173	.002
	FS			.133	.016
Perceptual Accuracy	pollution	.146	.132	-.181	.001
	CA			.256	.000
	SES			.180	.001
RHD	pollution	.388	.378	-.333	.000
	CA			.487	.000
	SES			.118	.009
LHD	pollution	.279	.267	-.294	.000
	CA			.412	.000
BHD	pollution	.206	.193	-.231	.000
	CA			.343	.000
	SES			.110	.032
IQ	pollution	.173	.160	-.393	.000

a. Predictors: (Constant), FamilySize, pollution, Gender, CA, SES

The major findings of multiple regression analysis between neuropsychological variables and intervening family variables of school-going children were:

1. The value of adjusted R Square (0.165) reveals that a total of 16.5% variance was caused by all the five predictor variables in determining the DSF/ attention ability of school-going children. Out of this 16.5%, about 12% of variance was caused by AAP and the rest 4% was caused by age variable. The other three variables caused negligible variance.

2. A total of 32.6% variance was caused by all the five predictor variables in determining the executive function/ working memory (DSB) of school-going children. Out of this about 17.31% of variance was caused by AAP and 7.13% was caused by SES and 6% by age and 2.98% by gender variable. The family size caused negligible variance in case of executive function.

3. A total of 21.5% variance was caused by all the five predictor variables in determining the Vocabulary scores of school-going children. Out of this almost equal percentage (7%) of variance was caused by AAP and age variables. 3.2% of variance was caused by gender and 3.76% of variance was caused by SES. The family size caused negligible variance in case of Vocabulary.

4. The value of adjusted R Square (0.364) reveals that a total of 36.4% variance was caused by all the five predictor variables in determining the visuospatial ability (BD) of school-going children. Out of this only 7.31% of variance was caused by AAP and 24.59% was caused by age and 3.12% by gender. The other two variables; SES and family size caused negligible variance.

5. A total of 16.6% variance was caused by all the five predictor variables in determining the immediate recall memory of school-going children. Out of this, 9.73% of variance was caused by AAP. 3.85% of variance was caused by age and 1.72% of variance was caused by gender and 2.36% by SES.

6. In case of both delayed recall and recognition memory, AAP was found to show no significant association with them as also revealed by the ANNOVA test results. Chronological age was the major factor causing about and 3.29% of variance in delayed recall and recognition memory respectively.

7. In case of perceptual accuracy (Coding test), only 13.2% variance was caused by all the five predictor variables in determining the perceptual accuracy of school-going children. Out of this only 3.73% of variance was caused by AAP and 6.89% was caused by age and 3.82% by SES. The other two variables; gender and family size caused non-significant variance.

8. A total of 37.8% variance was caused by all the five predictor variables in determining right hand dexterity (RHD) of school-going children. Out of this, about 12.01% of variance was caused by AAP, 24.56%of variance was caused by age and 2.12% of variance was caused by SES.

9. A total of 26.7% variance was caused by all the five predictor variables in determining left hand dexterity (LHD) of school-going children. Out of this, about 9.14% of variance was caused by AAP and 17.68% of variance was caused by age.

10. A total of 19.3% variance was caused by all the five predictor variables in determining 'both hand dexterity' (BHD) of school-going children. Out of this, about 5.82% of variance was caused by AAP, 12.29% of variance was caused by age and 1.75% of variance was caused by SES.

11. As revealed by the adjusted R Square values (0.160), a total of 16% variance was caused by all the five predictor variables in determining IQ of school-going children. AAP was the only significant predictor variable causing 15.56% of variance in Intelligence of school-going children.

Discussion of Results:

The obtained correlation coefficients revealed that there was a negative association between all the scores of school-going children on various neuropsychological variables and exposure to PM_{10}. A positive and significant correlation could be observed between various neuro-psychological variables and other personal & family variables like CA, gender, SES and family size. Further to calculate the percentage/ proportion of variance due to AAP and other personal & family variables, the multiple regression analysis was performed.

For carrying out multiple regression analysis, AAP was taken as main predictor variable and the other important covariates affecting the neuropsychological performances of children were age, gender, SES and

family size. These covariates were also treated as predictor variables and twelve neuropsychological measures were taken as criterion or dependent variable.

Neuropsychological measures like IQ, attention, executive function, vocabulary, immediate recall, RHD and LHD revealed moderate associations with AAP. Ambient air pollution accounted for about 7% to 15% of variance in these neuropsychological measures.

However, in case of all the variables involving motor coordination/ eye-hand coordination like visuo-spatial ability, perceptual accuracy and manual dexterity variables (RHD, LHD, and BHD), chronological age was found to be a dominating factor showing about 6.8% to 24% of variance in determining these neuropsychological measures. Maturity of various body muscles play an important role in activities involving motor coordination therefore, age could have been an important determining factor behind performance on visuo-spatial ability (block design test), perceptual accuracy (coding test) and manual dexterity test items.

Although slightly less robust, measures of visuo-spatial ability, perceptual accuracy and BHD were also found to be associated with pollution. About 7.3%, 3.73% and 5.82% of variability in visuo-spatial ability, perceptual accuracy and BHD scores respectively accounted for AAP.

In case of delayed recall and recognition memory, no significant association was found with AAP.

Gender was found to be accounting for 2.98%, 3.2%, 3.12% and 1.72% of variability in executive function (working memory), vocabulary, visuo-spatial ability and immediate recall (short-term) memory scores of school-going children respectively. A positive correlation reveals that school-going boys were found to be more competent in working memory, immediate recall memory, vocabulary and visuo-spatial ability as compared to the school-going girls.

The hesitation in girls of lower SES due to social stigmas attached with greater participation in such creative activities could be the reason behind lower scores of girls in these areas. In lower SES Indian societies, the boys are more encouraged for their performances in school and extracurricular activities. Greater participation of boys in social activities could be the other reason behind greater scores of boys on vocabulary as compared to the girls.

Although very meager, SES of school-going children also showed some significant associations with certain neuropsychological measures of school-

going children. SES of school-going children was found be accounting for 7.13%, 3.76%, 2.36%, 3.82%, 2.12% and 1.75% of variability in working memory, vocabulary, immediate recall, perceptual accuracy, RHD and BHD scores of school-going children respectively. All the associations were positive as shown by positive beta and correlation coefficient values. Out of the total sample of school-going children, the lower income group (SES) scored less on working memory, vocabulary, immediate recall, perceptual accuracy, RHD and BHD tests as compared to the higher SES school-going children. Higher motivation and greater opportunities being provided to the children in higher income group/ SES could be the reason behind better scores of children on these test items.

Family size could not reveal any significant ($p>0.05$) impact on any of the neuropsychological measures.

Chapter-4

Summary and Conclusion

The very complex structure of human nervous system, having specialized central and peripheral nervous cell functions makes it highly susceptible towards exposure to toxic chemicals of the ambient air. The constrained ability of the nerve tissues to replace or regenerate in case of cell death (WHO, 2001) makes the neurotoxicity of ambient air pollution chronic and devastating. The present research is an attempt to explore the impact of the ambient air pollutant; PM_{10} on the neuropsychological development of infants and young children of lower socio-economic status; one of the most vulnerable populations residing near busy roads and factories. In such areas, one of the major air pollutant particulate matter (PM_{10}) is found to be crossing the standard limit of 60 $\mu g/m^3$ (CPCB, India). Particulate matter has recently been reported as the ninth leading risk factor in 2010 for global disease burden (Lim SS, et al, 2010).

Ambient particulate matter was considered especially for the study as these inhalable particles have been recognized as one of the most deleterious air pollutants comprising of black carbon, sulphates, nitrates, minerals, dust etc.. Due to their minute size they may penetrate deep into the lungs and enter CNS through bloodstream. Particulate pollution is found to be a causal factor behind developmental delays, attention disorders (ADHD & ASD) among children (Siddique et al, 2011; Newman et al, 2013) and neurodegenerative diseases like Alziehmer's and Parkinson's disease (Block and Calderon- Garciduenas, 2009).

The research is a unique ex-post-facto field study. The objective of the research work was to assess the ambient air quality of Kanpur city and to study the impact of prenatal exposure to ambient air pollution on neuropsychological developmental aspects of children of three consecutive age groups; infancy (0-2 years), preschool (2-6years) and school-going (6-12 years). The confounding effect of other major socio-demographic factors; chronological age (CA), socio-economic status (SES), gender and family size on the neuropsychological development of children was also investigated.

Kanpur city; a highly polluted city of North India as well as having global ranking of fourth most polluted city (WHO, 2015) was considered as the

locale for study. Exposure to ambient air pollution was assessed in terms of PM_{10} levels using the six year (2011-2016) records of environmental monitoring data of state pollution control board (UPPCB). The city was divided into three levels on the basis of PM_{10} levels; low polluted (PM_{10} twice the standard value of 60μg/m^3), moderately polluted (PM_{10} thrice the standard value of 60 μg/m^3), and highly polluted (PM_{10} four times the standard value of 60μg/m^3). An area on the outskirts of the city, away from the city traffic and industries, surrounded by greenery, having PM_{10} within the standard limits (60μg/m^3) of National Air Quality was considered as the background area or control group.

After categorization of the city into four areas, a total of 720 healthy and full-term children; 25 infants, 80 preschoolers and 80 school-going children from each of the four areas were selected through purposive random sampling. Special care was taken to select the infants and children whose mothers have been residing in the study areas since five years at least. Children from the households in the area within one kilometer of aerial distance from the Ambient Air Quality (AAQ) Monitoring Stations of State Pollution Control Board (UPPCB) were only selected. Other major exclusion criteria for sample selection were children having any postpartum history or complications, children born to mothers consuming alcoholic beverages, unusual amounts of meat, fish, chicken or chalk/ mud during pregnancy, born premature or children not vaccinated or infants from families having any history of mental illness or diseases.

To study the neuropsychological effect of ambient air pollution on children, the neuropsychological development of infants, preschoolers and school-going children residing in the three exposed areas; low, moderate and high pollution areas was studied and compared with that of the children residing in the background area. Three different approaches of assessment of neuropsychological development of children were used for three age groups;

1. Measurement of Motor and Mental Developmental Quotients (DMoQ & DMeQ) (for 0-2 years/ infants through Indian Adaptation of Bayley's Scale for Iinfant Development (BSID); Developmental Assessment Scale for Indian Infants (DASII) by Dr.Pramila Pathak)
2. Measurement of Intelligence Quotient (IQ) and its factors through the use of a detailed IQ test (for 3-6 years through the use of Indian Adaptation of Stanford Binet (SB) Test by Kulshreshtha)
3. Measurement of various domains of neuropsychological development

through the use of short domain specific tests in form of a test battery (for 7-12 years)

Taking consideration of the language, culture and social behavior, the Indian adaptation of the psychological tests extensively used for the study of impact of air pollutants like PM, SO_2, NOx and PAH on children were selected. For school-going children, higher level mental functioning tests assessing the domains of attention (Digit Span Forward, DSF: part of Malin's test), executive function (Digit Span Backward, DSB: part of Malin's test), vocabulary knowledge (part of SB test), visuo-spatial ability (block design: part of Malin's test), immediate and delayed recall memory, recognition memory (part of PGI Memory test), processing accuracy (coding: part of Malin's Test) and manual dexterity (right hand; RHD, left hand; LHD, both hand; BHD) were used.

A self-prepared interview schedule was used for collection of personal, family details, the prenatal history, lifestyle factors, dietary habits, presence of any subjective symptoms associated with air pollution and other socio-demographic details of the sample. The modified Kuppuswamy's scale was used to analyse the socio-economic status of the families. Children of similar income group were selected to match them on income, education and dietary factors. The children and their mothers were contacted at their respective houses, Anganwadi centres and Primary Schools as per the age group and availability.

To proceed with the investigation, it was hypothesized that “there will be no significant difference between the mean scores of various neuro-psychological measures of children of various exposed and background areas of Kanpur”.

After approval from a DCGI registered ethics committee of the city and informed consent of the parents, data was collected from the parents and the children at their houses or schools.

After collection of the data, it was analysed using various statistical methods like mean, analysis of variance (ANOVA), odds ratio, correlation and multiple regression analyses. Majority of the infants and preschoolers belonged to lower-middle SES, the school-going children were mainly from upper-lower SES. Most of the children belonged to families having 5 to 8 family members. The mean age of infants was 12.7 months, of preschoolers 4.3 years and of school-going children 9.5 years.

Conclusion regarding the effect of ambient air pollution on neuro-

psychological development of children of the three age groups; infants, preschoolers and school-going children are being made in the following sequence :

a. Comparison of mean scores of children of various exposed and background areas on neuropsychological tests using ANOVA,

b. Comparison of number of lower performances of children of various exposed and background areas on neuropsychological tests using chi-square test and odds-ratio calculations,

c. Correlation of scores of children of various exposed and background areas on neuropsychological tests with various socio-demographic variables,

d. Multiple regressions of scores of children of various exposed and background areas on neuropsychological tests and various socio-demographic variables.

Effect of ambient air pollution on different aspects of neuropsychological development of infants (0-2 years) :

Among the three stages studied in the present research work; infancy, early childhood and late childhood, infancy is said to be the most critical and sensitive stage of development. As compared to other animals (rodents etc.) humans have considerably more prenatal maturation of their nervous system (Rice and Barone, 2000). Thus, all the environmental factors affecting the neural development of the child during prenatal development may reflect their impact on the infant's psychomotor and mental development. As a matter of fact, gross measures of human brain growth increase for at least 2-3 years after birth. The growth rate of the brain as a whole, as measured in volume, peaks approximately 1.1 years after conception or approximately 4 months after birth (Koop et al, 1986). This makes the infancy stage highly vulnerable towards the environmental exposures like AAP.

From the findings of the present study, it may be concluded that the overall motor (DMoQ) and mental development (DMeQ) of infants were found to be adversely affected by the ambient air pollution of the city. The mean scores of both the DMoQ and DMeQ of infants of various exposed areas and the background area were found to be significantly ($p<0.000$) different as revealed by the ANOVA.

The five aspects of motor development studied through motor scale of DASII were neck control, body control, locomotion-1 (co-ordinated movements),

locomotion-2 (skills) and manipulation.

On comparison of number of lower performances of children of various exposed areas and the background area on DASII, the overall motor development of infants was found to be significantly different. The whole body control and the coordinated movements involved in walking and climbing steps of exposed areas as compared with the background area, were found to be significantly different. Prenatal exposure to ambient air pollution which has often been linked to retarded and delayed growth of the fetus (Rich DQ et al, 2009; Choi H et al, 2008; Xu X, Sharma RK, et al, 2010; Wang X et al, 1997) was found to be associated with poor coordination of muscles and nerves for body control and movements.

No significant difference was found in case of neck control and motor manipulative skills of infants of exposed areas and the background area. Infants of all the four study areas were reported to have full control over neck movements like holding the head steadily etc.. However, in case of the higher order manipulative motor skills like clapping, throwing ball, holding pellets/ cubes and rotating wrist the infants of all the study areas could not perform well. Similar evidences of no significant psychomotor development index at 12 and 24 months of age were reported by Kim E, et al (2014) in his prospective birth cohort study on the effect of prenatal exposure to the air pollutants, PM10 and NO2 on infants (0-24 months).

Similar to the motor development, on comparison of lower performances of infants of various exposed areas and the background area on DASII mental scale, the overall mental development of infants was also found to be significantly different.

The ten aspects of mental development studied through mental scale of DASII were visual cognizance, auditory cognizance, reaching-manipulating-exploring, memory, social interaction- imitative behavior, language-1: vocalization-speech-communication, language-2: vocabulary-comprehension, understanding of relationship, differentiation by use, shapes and movements and manual dexterity.

Air pollutants like particulate matter (PM) have been found to easily enter the human brain directly through nasal olfactory mucosa or through leakage in blood brain barrier due to its fine/ minute size (Genc,S. et al, 2012; Lucchini et al, 2012; Oberdoster et al, 2004; Peters et al, 2006). Oxidative stress and inflammation are the two major underlying processes by which air pollutants like PM are believed to exert their toxicity on brain or the Central Nervous System (Mohan Kumar et al, 2008; Weldy et al,

2011). The prefrontal, parietal and occipital cortexes in the brain control the mental processes of visual and auditory cognizance, memory and language acquisition of children (Pathak, 2001). As per the assumptions in the present study, toxicity of PM10 was not found to affect the basic sensory processes like 'visual cognizance' and 'auditory cognizance' of infants. However, in using those basic sensory processes at higher levels, in coordination with each other i.e., in reaching-manipulating-exploring and learning to vocalize-produce speech & communication (language development), significant differences were observed in the lower performances of infants of the three exposed areas as compared to the infants in background area. The results were in consistence with the findings of earlier researches (Perera etal, 2006, Guxens et al, 2012; Kim. E. et al, 2004; Lovasi et al, 2014).

On the items of memory sub-test, infants in all the three exposed areas; low moderate and high revealed similar performance. Although, the number of lower performance in exposed areas was found to be significantly different from the number of lower performances in background area. As also reflected by Piaget (1970) in his clinical studies on infants, gradually till the end of two years, the child develops the concept of object permanence and selective attention leading to perceptual products to store in memory.

Ambient air pollution was found to be negatively correlated and chronological age of infants was found to be positively correlated with various aspects of motor and mental development of infants. However, the overall mental and motor development of infants only showed a substantial correlation (r not more than 0.35, $p<0.01$) with AAP. The correlation of all other motor and mental development variables with AAP was very weak (r not more than 0.2) except in case of some aspects (Differentiation by use, shapes and movements, manual dexterity and locomotion-2) of motor development a stronger correlation of r=0.5 was found. Similarly, motor development was the only aspect where gender was found to show some impact on infants. Thus, the boys of all the study areas were found to perform somewhat better than the girls.

Effect of ambient air pollution on different aspects of neuropsychological development of preschoolers (3 - 6 years):

The early exposure to environmental pollutants may interfere with critical developmental processes (i.e., formation of neurons, migration of neurons to various regions of brain, differentiation of neurons, formation of synapses

and myelination of neurons) of the nervous system. Interference with any of these developmental processes can affect any of the motor or cognitive functions. Longitudinal studies suggest that younger children may be particularly susceptible to the environmental influences on intelligence. Although heritability becomes a strong predictor of IQ as children grow older, these studies estimated that heritability of IQ contributes about 30% in early childhood and increases to more than 50% in adulthood (Brant et al,2009; Deary et al 2007; Van Soelen et al, 2011).

In the present study, the IQ of preschoolers was found to be adversely affected by the exposure to PM_{10}. As revealed by the ANNOVA, a significant difference ($p<0.05$) was found in the mean IQ values of preschoolers of exposed area and that of the background area.

The six aspects of intelligence of preschoolers studied through sub-tests of SB test were; visual perception, motor co-ordination, language development, immediate memory, concept formation and reasoning.

On comparison of number of lower performances of the preschoolers of exposed areas and the preschoolers of background area on various sub-tests of SB intelligence test (Indian Adaptation by Kulshreshtha), visual perception, motor coordination and reasoning were the three aspects which revealed significant differences. The odds of performing lower on these three aspects of intelligence in various exposed areas were three to four times higher than that of background area. Similar results of lower non-verbal IQ, visuo-motor performance (Harris M H et al (2015)) and lower reasoning (Edwards et al., 2010) due to traffic related air pollution (TRAP) has been reported earlier also.

Language development & comprehension, concept formation and full IQ were the aspects of intelligence in which the preschoolers exposed to only high pollution area showed significant difference as compared with that of background area. No significant differences were found in preschoolers exposed to low and moderate pollution areas as compared with preschoolers of background area. Reason behind no remarkable difference in language development and concept formation in low and moderate pollution areas could be higher dependency on other factors like opportunities provided by family and school and motivation from the family in learning the language and basic concepts as compared to the maturational factor.

Immediate Recall was the only aspect of intelligence which showed no significant difference in the number of lower performances of preschoolers of exposed areas and the background area.

Although not so strongly correlated, ambient air pollution was found to be negatively and chronological age of preschoolers was found to be positively correlated with various aspects of development of preschoolers. Very weak correlation between few aspects of neuropsychological development and age as well as SES factors ($r<0.14$) were reported. Gender and family size were not found to be significantly correlated ($p>0.05$) with any aspects of neuropsychological development of preschoolers.

Effect of ambient air pollution on different aspects of neuro-psychological development of school-going children (7-12 years):

Development of human nervous system is known to extend from the embryonic period through adolescence. Various parts of the brain develop at different times and have different periods of vulnerability based on the temporal and regional maturation mediated through a multitude of developmental processes. Formation of neurons, migration of neurons to various regions of brain, differentiation of neurons, formation of synapses and myelination of neurons are the major developmental processes of human nervous system (Rice and Barone, 2000). Thus, the school-going age also becomes a vulnerable stage being affected by environmental chemical exposures.

During the school-going stage that is the late childhood stage, the child is able to perform well on various motor and mental skills as the children have matured enough and developed the skills sufficiently to perform on a wide variety of neurobehavioural tests. In addition, they are capable of cooperating better for more functional tasks due to a greater understanding of the concepts as compared to the infants and early childhood age children (preschoolers). Thus, the school-going children were given a variety of mental tasks with precise measurement of performance to observe the toxic effects of ambient air pollutants if any.

In the present study, school-going children of government primary schools of various study areas were considered as the students of the lower income group are found to be more at risk of health hazards associated with local air pollution and other deprived conditions (Adamkiewicz et al. 2011; Hutch et al. 2011; Jackson and Tester.2008; Ou et al. 2008). The classrooms inside the government schools were found to be very airy and well ventilated leading to an assumption that the air quality inside the classrooms might be at par with the air quality outside. Out of the six hours of school timings, for about three hours, the children were found to be engaged in classroom activities and half of the time the children were mostly involved in outdoor

activities. The outdoor play area in most of the schools was more than half of the total area of the school. The ambient air quality inside the school boundary was thus very much similar to the AAQ of the nearby areas. The physical activity of children at school may be increased due to physical education and play activities and their breathing rates and dose of inhaled pollutants may increase during school hours (McConnell et al. 2010).

Neuropsychological assessment revealed that various neuropsychological measures; full IQ, attention, executive function, vocabulary, visuo-spatial ability, immediate recall memory, processing accuracy and finger dexterity (right hand: RHD, left hand:LHD and both hands:BHD) except 'delayed recall' and 'recognition memory' of school-going children were adversely affected by the ambient air pollution. Both ANOVA and correlation analysis reported same results. The F-values reported significant difference ($p<0.01$) between the mean scores of the school-going children of exposed areas and the background area. The correlation between various neuropsychological measures (full IQ, attention, executive function, vocabulary, visuo-spatial ability, immediate recall memory, processing accuracy, finger dexterity) and ambient air pollution was found to be significant ($p<0.01$) and negative. Similar results of lowered cognitive functions during late childhood age due to air pollution were earlier reported by Sunyer J. (2015); Suglia et al (2008); Wang et al (2009) and Calderon G. (2008).

Comparison of number of lower performances of school-going children of various study areas on various neuropsychological tests through chi-square test also depicted similar results. The lower performances of various neuropsychological measures except 'delayed recall' and 'recognition memory' of school-going children of the three exposed areas were found to be significantly more and different as compared to that of the background area. However, in case of Delayed Recall the higher prevalence of lower performance in school-going children exposed to high pollution area (HPA) solely as compared to the background area was found to be statistically significant (UA vs HPA, OR=8.7, $p<0.01$).

The risk associated with lower performance on various neuropsychological measures (except 'delayed recall' and 'recognition memory') was in accordance with the level of PM10 in low, moderate and high polluted areas as compared to the background area. The higher the level of PM10 of the area, the higher was the risk associated with lower performance of school-going children on the neuropsychological tests as compared to the background area.

Recognition memory, the most basic form of memory (ichonic memory) involving visual cognizance of school-going children was not found to be significantly associated with ambient air pollution. Findings were consistent with the results of Harris MH. et al (2015). Design memory and picture memory scores measured by Wide Range Assessment of Memory and Learning (WRAML) test did not differ substantially by major roadway proximity (TRAP) among children of 6 to 10 years of age in the study by Harris MH et al.

As far as delayed recall memory was concerned, Murre, JMJ (2013) and Vogel Mc, Collough & Machizava, (2007) in their studies reported that certain factors such as individual differences in neuromodulators like acetylcholine and dopamine could affect long term memory more than short term memory. The variations in neuromodulators (acetylcholine and dopamine) could be the reason behind no significant adverse affect of ambient air pollution ascertained on delayed memory of school-going children.

Although children from similar income group/ SES were selected for the study, certain variations were found in the socio-demographic characteristics of the sample of school-going children. Due to this reason significant correlations were obtained between the performance on various neuropsychological tests and certain personal & family variables. The confounding effect of these major socio-demographic factors; chronological age, SES, gender and family size on the neuropsychological development of children was investigated through multiple regression.

Ambient air pollution along with chronological age, gender, SES and family size were considered as predictor variables and twelve neuropsychological measures; IQ, attention, executive function, vocabulary, immediate recall, delayed recall, recognition memory, visuo-spatial ability, perceptual accuracy, RHD, LHD and BHD were taken as criterion or dependent variable for the multiple regression analysis.

Neuropsychological measures like IQ, attention, executive function, vocabulary, immediate recall, RHD and LHD revealed moderate associations with AAP. Ambient air pollution accounted for about 7% to 15% of variance in these neuropsychological measures.

Although slightly less robust, measures of visuo-spatial ability, perceptual accuracy and BHD were also found to be associated with air pollution. About 7.3%, 3.73% and 5.82% of variability in visuo-spatial ability, perceptual accuracy and BHD scores respectively accounted for AAP.

Chronological age was found to be a dominating factor showing about 6.8% to 24% of variance in determining these neuropsychological measures involving motor coordination/ eye-hand coordination. Maturity of various body muscles were found to be an important detrimental factor behind performance on visuo-spatial ability (block design test), perceptual accuracy (coding test) and manual dexterity (RHD, LHD & BHD) test items.

Although very meager, SES and gender of school-going children also showed some significant associations with certain neuropsychological measures of school-going children. SES was reported to affect more number (six) of neuropsychological measures (working memory, vocabulary, immediate recall, percetual accuracy, RHD, BHD) as compared to gender affecting only four variables (working memory, vocabulary, immediate recall, visuo-spatial ability). Executive function/ working memory and vocabulary were mainly reported to be positively associated with both SES and gender. Substantial variations (3% to 7%) in SES and gender accounted for variability in the scores of 'working memory' and 'vocabulary'.

Higher motivation and greater opportunities being provided to the children in higher income group/ SES could be the reason behind better scores of children on these test items. As reported earlier also lower income group being more deprived and disadvantaged as compared to the higher income group were more at risk of lower mental abilities (Johnson et al, 2011; Lloyd et al, 2010).

Boys were found to score more on 'working memory', the capacity to learn and manipulate stimuli as compared to the girls. Greater confidence and risk taking behavior among boys being promoted in our society could be the major underlying factor. Similarly, greater socialization of boys as compared to the girls could be the causative factor behind better performance of boys on vocabulary test as compared to the girls.

Implications of the present research could be of great importance and concern for the betterment of mental and motor performances of future generations of our society. If proper attention is paid to the cognition of the infants and young children taking into consideration of these important environmental factors, these children could excel in various fields and horizons of life leading to overall development of a nation.

Limitations of the study :

1. Due to lack of sufficient time, longitudinal research on same group of children for longer duration i.e., starting from prenatal development till 12 years of age could not be performed.

2. Personal monitoring of air pollutants inhaled during prenatal development could not be executed as it required greater medical supervision and sufficient time.

3. Sample size was small in case of infants as, infancy is a stage which requires sufficient time, patience and understanding for assessment of motor and mental development. However, the tool used for the study of infants (DASII) was very exhaustive and covered detailed evaluation of mental and motor development of infants starting from neck control to language development.

Suggestions for future research:

1. Longitudinal researches having 10-11 years feedback should be conducted to study the cumulative effect of ambient air pollution on young children in developing countries.

2. An in-depth study of the neurological processes involved in the developmental disorders like ASD and ADHD among children through the combination of neuroimaging and neuropsychological functioning is required.

3. There is a need for multidisciplinary approach for studying the mental health hazards of ambient air pollution involving health professionals, paediatricians, behavioural scientists, psychologists and environmentalists.

Some recommendations for general public, government and non-government organizations for reducing the effects of ambient air pollution on the mental and motor performance of infants and children:

1. By reducing air pollution itself in several ways like by using public transportation in place of private transport, not burning garbage outside houses or in streets, switching over to more environment friendly resources of energy like solar energy and CNG.

2. In addition to proper provision and maintainenance of roads, public transportation and parking system in the city, strict implementation of the policies and measures regarding vehicles and industries contributing to pollution in the city, housing and garbage disposal parameters to be formulated by the government. Similar step of reducing vehicular air pollution has recently been taken by

Government of India by investing more in quality improvement of public transport through metro and other superfast trains in various cities.

3. Increasing public awareness about deteriorating air quality (especially those residing in the areas near factories and roadside areas having high traffic) and its impact on the physical as well as mental health of their children.

4. Developmental delays among children if diagnosed at an early stage could be taken care of through nutrition and enhancement of their cognitive & motor skills. Parents of low SES should be made aware about role of good nutrition especially foods rich in antioxidants, in cognitive development of children. They should be given tips on how to engage their children in various activities for enhancing their cognitive abilities like memory, reasoning, visuospatial understanding, processing speed and accuracy. Similar efforts of awareness of parents, teachers and children of the study areas were made by the researcher herself. Workshops and group discussions on topics related to Ambient Air Pollution and its effect on the development of children were organized in the study areas for dissemination of measures for reduction of Ambient Air Pollution. The information for encouragement of various activities for cognitive and motor development of children in the study areas were disseminated through discussions, demonstrations and distribution of booklets prepared by the researcher.

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Annexure No. I (a)

IAP Growth Chart

Weight and Height Chart for Boys in India (0-18Years)

WEIGHT				HEIGHT		
Min	Mid	Max	Age	Min	Mid	Max
2.5	3.3	4.5	0	46	50	53.5
6	8	10	0.6	63	66	72
7.5	9.5	12	1	71	75	80
8.5	11	13.5	1.6	77	82	87
9.5	12	15	2	82	87	94
10.5	13	16.5	2.6	85	92	98
11.5	14	18	3	89	96	103
12	15.5	19	3.6	92	100	106
12.5	16	21	4	95.5	103	111
13	17	23	4.6	97	106	115
13.5	18	24.5	5	100	109	118.5
14	18.5	26	5.6	102	112	122.5
14.5	19	28	6	104	115	126
15.5	21	31	6.6	105.5	118	129.5
16	22	33.5	7	109	120.5	132.5
16.5	23	36	7.6	112	123	135.5
17.5	25	39.5	8	114	126	139
18.5	26	42	8.6	116	129	142
19	27	45.5	9	119	131.5	145.5
20	28	48.5	9.6	121	134.5	148.5
21	31	51.5	10	123.5	137	151.5
21.5	32.5	55	10.6	126	140	154.5
22.5	34.5	58	11	128	142	157
24	37	62	11.6	130.5	145.5	160.5
25	39	66	12	133	148	163.5
26	41	69.5	12.6	136	151	166.5
27.5	43	72	13	138	154.5	170
29	46	75.5	13.6	141	157	173
30.5	48	78	14	143	160	175.5
32.5	51	81	14.6	146	162	177.5
34.5	53	83	15	148	164	179.5
36	55	84.5	15.6	150	166.5	181.5
37	56.5	86	16	152	168	183
38.5	58	86.8	16.6	153	170	184
39.5	59	87.5	17	155	171	184 .5
41	60.5	87.5	17.6	156.5	172.5	186
42	61.5	88	18	158	173.5	186.5

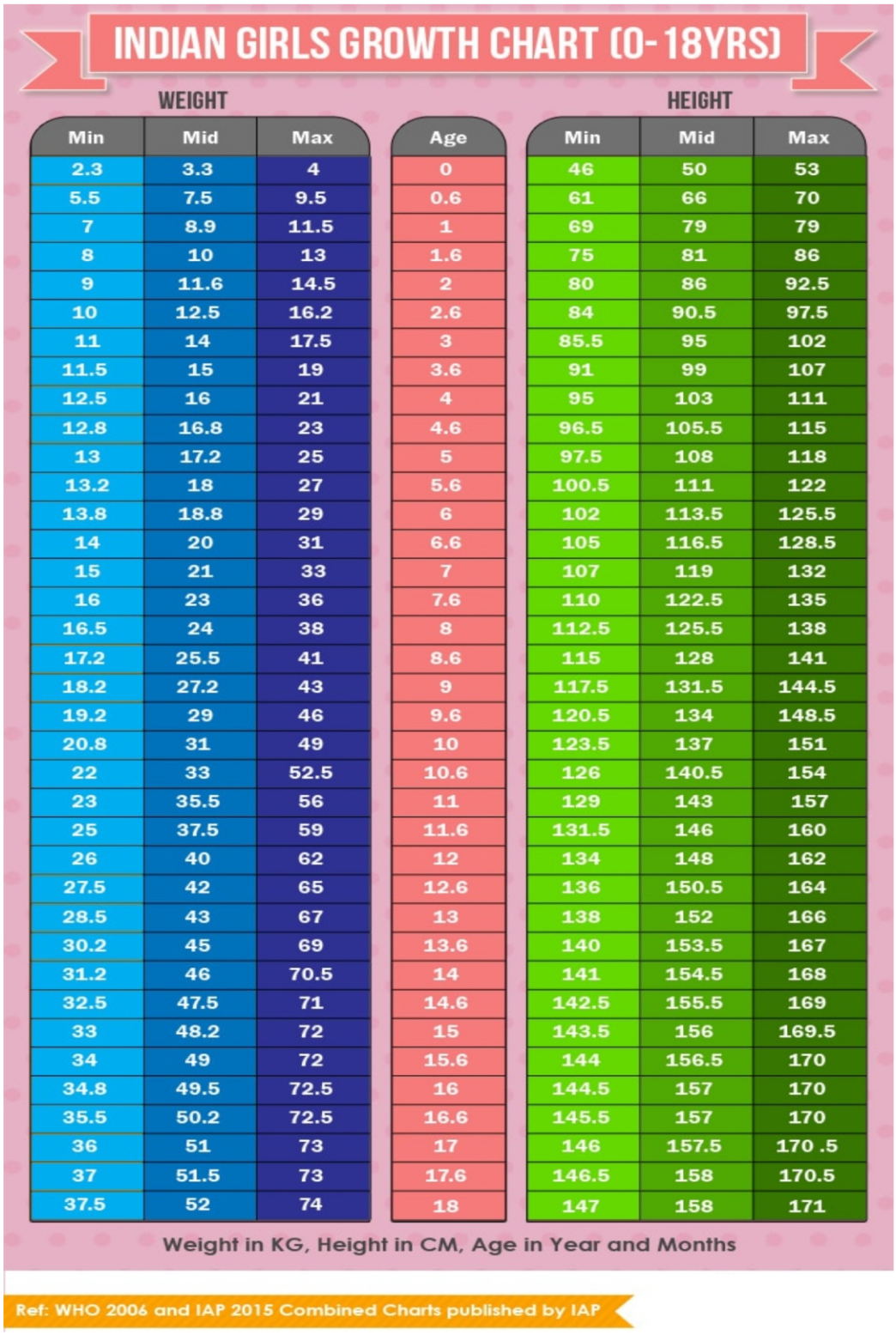
Weight in KG, Height in CM, Age in Year and Months

Ref: WHO 2006 and IAP 2015 Combined Charts published by IAP

Annexure No. I (b)

IAP Growth Chart

Weight and Height Chart for Girls in India (0-18Years)



Annexure No. II

Consent form from the parents.

UGC Post Doctoral Research Work

Title of Study: "Neuropsychological Effects of Ambient Air Pollution on Infants & Children"

Researcher:
Dr. Madhulika Sharma,
12/411-A,
Gwaltoli, Behind Church,
Kanpur-208001.
Contact No.: 8726259999.

Research Centre:
Department of Home Science,
Juhari Devi Girls PG College,
Canal Road,
Kanpur.

Consent Form for Psychological Testing of Infants and Children for their Mental and Motor Development to be signed by the Parents

Name of the Respondent/ Mother :_____

This is a research study. Please feel free to ask questions any time. The purpose of the research is to study the effect of air pollution on infants and children of Kanpur city. The researcher is going to assess the mental and motor development of your child using a standardized test battery. The test will take about 45-60 minutes. At any point of time your child can refuse to participate in the study. Prior to the test, the mother of the child will be asked to complete a personal information and prenatal history sheet of the child.

Any information collected from you will be treated confidentially and only used for the purpose of this study. If you agree you would sign below:

I agree to the researcher working on "the effect of air pollution on children of Kanpur" assessing the mental and motor development of my child and enquiring about his/her family history.

Name of the Child : _____

Signature of Mother :_____

Signature of Father : _____

Signature of Interviewer : _____

Date : _____.

Annexure No. III

Interview Schedule for General Information of Mothers and Children

(Hindi version was used for Survey)

(To be answered by the mother only)

1. Name of the child/ subject:
2. Age :
3. Sex :
4. Address :
5. Years of residence in the area :
6. Age of Parents :
   a) Father :
   b) Mother:
7. Education of Parents:
   a) Father : Illiterate/ Just Literate/ Primary/ Junior Secondary/ High School/ Intermediate/ Graduate/ Post Graduate/ Other (specify)
   b) Mother: Illiterate/ Just Literate/ Primary/ Junior Secondary/ High School/ Intermediate/ Graduate/ Post Graduate/ Other (specify)
8. Occupation of Parents :
   a) Father : Farming/ Labourer/ Business/ Service/ Other (specify)
   b) Mother: Housewife/ Teacher/ Labourer/ Business/ Service/ Other
9. Type of Family : Nuclear/ Joint
10. Number of members in the family :
    a) Number of Independent Members :
    b) Number of Dependent Members :
11. Monthly Income of the family :

Details of the Child's Prenatal and Postnatal Development

12. Date of Birth of the child:
13. Birth order, whether the child is first born/ second/ third/ any other
14. Was it a fullterm/ preterm delivery:
15. Place of delivery : Hospital/ Home
16. Type of Birth: Normal/ Caesarian/ Breech/ Instrumental
17. Complications of Delivery : Gestational diabetes/ hypertension/ any other (specify) / none
18. Whom do you consult for prenatal care/ delivery during this pregnancy :

    An Obstetrician/ Family Doctor or a Physician/ Midwife or a Nurse/ Any other type of health professional/ None of these
19. Do you have any previous history of miscarriage/ abortion/ still birth/preterm birth: Yes/ No
20. Age of mother at the time of birth of the child:
21. Weight of the child at the time of birth : _____kg
22. Length of the child at the time of birth: _____ inches
23. Have you had any X-ray during this pregnancy : Yes/ No. If yes, then when?
24. Have you taken any kind of medicines/ drugs during this pregnancy? If yes,

    list them _____
25. a. How many hours per day did you work during this pregnancy?

	2-3 hours	4-5 hours	6-7 hours	More than 7 hours
Household work				
Office work				
Any other work (specify)				

25. b. Duration of time spent by you; outdoor or indoor during the day (specify):

Morning	**6am-8am**	**8am-10am**	**10am-12pm**
Outdoor/ Indoor			
Afternoon	**12pm-2pm**	**2pm-4pm**	**4pm-6pm**
Outdoor/ Indoor			
Evening	**6pm-8pm**	**8pm-10pm**	
Outdoor/ Indoor			

26. During this pregnancy, have you eaten more, less or about the same of the following foods or did not eat before or during pregnancy?

Food Items	**Eat More**	**Eat Less**	**Eat about the same**	**Did not eat before or during pregnancy**
Fish				
Chicken or Meat				
Coffee				
Alcoholic drinks				
Vitamin or Mineral Supplements				
Chalk/ Mud				

27. How many people (including family members, friends, anyone else or you) smoke inside your home most days?

0___ 1___ 2___ 3___ 4 or more___

28. What is used for cooking food in your home?

LPG___ Stove with kerosene oil___ Chulha___Any other (specify)___

29. What is the source of drinking water : Municipal/ Underground/ RO or filtered water/ Any other (specify)

30. Do you or any other relative of yours have the following :

	You	Child's father	Child's brother or sister	Child's grandparents, aunts or uncles
Diabetes				
Asthma				
Eczema				
Food allergy				
Allergies to pollen, dust, animals, latex or anything else				
Congenital heart disease				
Neural tube defects like spina bifida				
Chromosomal disorder like Down's syndrome				
Mental retardation/ Autism				
Muscular dystrophy/ Physical disability				
Genetic disorder like sickle cell anaemia				
Haemophilia or other bleeding disorder				
Thyroid disease				
Tuberculosis				
STD like AIDS				

Feeding practices of the child

31. First milk/ Colostrum given to the child after birth: Yes/ No

32. Age of the child when you stopped breast feeding the child :

33. Age of the child when you started giving him top/other type of milk:

34. The other type of milk given at that time : Cow/ buffalo/ Formula milk/ Any other (specify)

35. At what age other food items (other than milk) were introduced :

36. Any supplementary food item/ vitamin or mineral supplements being given to the child since then :

37. General diet pattern of the child : Please fill the details in the 'General Diet Chart'.

Food preparation Meal	Cereal preparation	Pulses preparation	Milk(mention the type; cow, formula etc.)	Milk preparation	Meat & fish	Vegetable	GLV	Fruit	Fast Food like maggi	Readymade food items like biscuit, dalmoth
Early Morning										
Breakfast										
Lunch										
Tea time/Evening										
Dinner										
Bedtime										

Immunization

38. Whether your child has been given the following vaccines or not :

1. BCG :
2. Oral Polio :
3. DPT :
4. Measles :
5. Any other :

Activity Pattern of the Child

Duration of time spent by the child; outdoor or indoor during the day (specify):

Morning	**6am-8am**	**8am-10am**	**10am-12pm**
Outdoor/ Indoor			
Afternoon	**12pm-2pm**	**2pm-4pm**	**4pm-6pm**
Outdoor/ Indoor			
Evening	**6pm-8pm**	**8pm-10pm**	
Outdoor/ Indoor			

Subjective Symptoms

39. Do you often observe any such symptoms in your child inside the house or whenever you take him/her outside :

1. Watery eyes :
2. Irritation in eyes :
3. Runny nose :
4. Nasal congestion :
5. Scratchy throat or cough :
6. Cold :
7. Fever :

40. Is your child suffering from any of these diseases? If yes, then since when?

1. Respiratory Disease like Asthma/ T.B./ Allergy for dust particles etc./ Bronchitis/ other
2. Gastro Intestinal Disease like Diarrohea/ Desentry/ Constipation/ other
3. Liver Disease like jaundice/ other
4. Heart Disease
5. Any other (specify)

Anthropometric Measurements of the child

1. Weight (Kg) :
2. Height (cm) :
3. Head Circumference (cm) :
4. Mid Upper Arm Circumference (cm) :
5. Chest Circumference (cm) :

Clinical Examination

1. General Appearance : Healthy/ Unwell/ Ill
2. Hair : Normal/ Abnormal or suffering from some disease (like lusterless)
3. Face : Normal/ Abnormal (like moonface/ pigmented)
4. Eyes : Normal/ Abnormal (like dry/ spotted)
5. Lips : Normal/ Abnormal (like cheilosis)
6. Tongue : Normal/ Abnormal (like red & soft/ magenta)
7. Teeth : Normal/ Abnormal (like mottled/ caries)
8. Gums : Normal/ Abnormal (like bleeding/ swollen)
9. Nails : Normal/ Abnormal (like pail/ pigmented)
10. Skin : Normal/ Abnormal (like dry/ wounded)

Annexure No. IV

SES Scale by Kuppuswamy (Modified 2017)

Education of head of family				**Score**
Profession or honours				7
Graduate or postgraduate				6
Intermediate or post high school diploma				5
High school certificate				4
Middle school certificate				3
Primary school certificate				2
Literate				1
Occupation of head of family				
Profession				10
Semi-profession				6
Clerical, Shop-owner				5
Skilled worker				4
Semi-skilled worker				3
Unskilled worker				2
Unemployed				1
Monthly income of family				
In 1976	In 1998	In 2007	In 2017 (January 2017 CPI)	
>=2000	13408	19844	>41430	12
1000-1999	6704-13407	9922-19843	20715-41429	10
750-999	5028-6703	7441-9921	15536-20714	6
500-749	3352-5027	4961-7440	10357-15535	4
300-499	2011-3351	2976-4960	6214-10356	3
101-299	677-2010	1002-2975	2092-6213	2
<=100	<676	<1001	<2091	1
Socioeconomic class				**Total score**
I	Upper			26-29
II	Upper middle			16-25
III	Lower middle			11-15
IV	Upper lower			5-10
V	Lower			<5

Annexure No. V

Record Sheet for SB Test (Hindi Version) for 6-12 years

Stanford Binet Test Hindi Adaptation (II to VI years)

Name of Child : ..... Sex : ..... C.A. : .....
Address : ..... M.A. : .....
Basal Age : .....to Ceiling Age :……. I.Q. : ……

S.N.	Mental functioning involved	Items			No. of correct items (all)	No. of items attempted(up to CA)
I.	**VISUAL PERCEPTION:**					
a)	Perception of Form & Objects	II (1)	II (4)	II-6(alt)		
		III(6)				
b)	Copying Shapes	III(6)	III-6(alt)	V (4)		
c)	Discrimination of shapes	IV (5)	IV-6(3)	IV(3)		
		V (1)	VI (3)	IV-6(2)		
d)	Paper Folding	V (2)				
e)	Copying knot	V (alt)				
				Total		
		Up to CA			**Above CA**	**Total**
	No. of correct items					
	No. of items attempted					
II.	**MOTOR CO-ORDINATION:**					
a)	Block building	II (4)	III (3)			
b)	Bead chain	III (1)				
c)	Copying shapes	III (5)	III-6(alt)	V (4)		
d)	Paper folding	V (2)				
e)	Copying knot	V(alt)				
f)	Button Sorting	III-6(5)				
				Total		
		Up to CA			**Above CA**	**Total**
	No. of correct items					
	No. of items attempted					
III.	**LANGUAGE DEVELOPMENT AND COMPREHENSION:**					
a)	By name	II (2)	II (3)	II-6(2)		
		II-6(3)	II (alt)			
b)	By use	II-6(1)	III-6(5)	II-6(4)		
		IV-6(alt	IV (4)			
c)	Through Objects	II-3	II-6(alt)			
d)	Picture Vocabulary	II-5	II-6(4)	III-(2)		
		III-6(2)	IV-(1)	V-(6)		
e)	Verbal Comprehension	III-6(1)	IV-6(5)	IV-6(6)		
		IV (6)				
f)	Vocabulary (words)	II (6)	VI (1)			
				Total		

		Up to CA			**Above CA**	**Total**
	No. of correct items					
	No. of items attempted					
IV.	**IMMEDIATE RECALL:**					
a)	Digits	II-6(5)	III (alt)			
b)	Pictures	III (4)				
c)	Objects	IV (2)	VI (2)			
d)	Sentences	IV (alt)				
				Total		
		Up to CA			**Above CA**	**Total**
	No. of correct items					
	No. of items attempted					
V.	**Concept Formation:**					
a)	Obeying commissions	II-6(6)	III-6(1)	IV-6(6)		
b)	Perception of relations	III-6(4)	VI (alt)			
c)	Shapes	III (5)	III-6(alt)	V (4)		
d)	Definitions	V (3)				
e)	Material	IV-6(4)				
f)	Number concept	VI (4)				
				Total		
		Up to CA			**Above CA**	**Total**
	No. of correct items					
	No. of items attempted					
VI.	**REASONING:**					
(a)	Comparison of;					
	a) Objects	III-6(3)				
	b) Shapes	IV-6(3)	VI (5)			
	c) Aesthetic comparison	IV-6(1)				
(b)	Comprehension of direction and routes	V (5)	VI (6)			
(c)	Giving reasons	III-6(6)	IV (6)			
				Total		
		Up to CA			**Above CA**	**Total**
	No. of correct items					
	No. of items attempted					